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AMERICAN WELDING SOCIETY

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Bridgeport Engineers Compare Welding With Riveting

(Reprinted from Dec. 6, 1928, issue, *Engineering News-Record*)

At a joint meeting of the Bridgeport Section, A.S.M.E., and the Engineers Club of Bridgeport, Conn., recently, both riveting and welding were openly discussed. Chauncey Hanna, president Hanna Engineering Works, Chicago, Ill., presented a film entitled "This Is the Age of Riveted Steel," showing methods of making rivets, the application of rivets in modern steel fabrication and the use of automatic riveting machinery that entirely eliminates the human element. E. Ewertz, for many years manager of the Moore plant of the Bethlehem Steel Co., stated that this human element exists in both riveting and welding, but it is his belief that the importance of the human element in welding is being overemphasized and that good welding rests more on proper design, materials, welding wire and welding machinery. Slides shown by Mr. Ewertz emphasized the simplicity of the welded structure and gave results of comparative tests on a 6-in. I-beam fastened respectively by welding and riveting to uprights at each end, in which the riveted structure failed at a loading of 60 tons with a deflection of 1 in., while the welded structure failed at a loading of 90 tons with a deflection of 3 in. Mr. Ewertz stated that sixteen of the largest shipbuilders in the United States used last year more than 24,000,000 cu. ft. of acetylene for cutting and welding and that one manufacturer, the Page Steel & Wire Co., sold several thousand tons of welding wire during 1927.

William Spraragen, secretary, division of engineering, National Research Council, told of the important research work being done by the welding industry. All three of the speakers admitted that both welding and riveting had their own field of application and that although the fields overlapped in many cases, there was plenty of business for both. In many jobs whether riveting or welding is to be used will be simply a matter of economy.

Journal Bound Volumes

The bound volumes of the JOURNAL for the year 1928 are now available. Each year the Society arranges to have bound a limited number of copies of the JOURNAL in attractive imitation black leather covers. A subject and authors' index is included. In this way the records of the Society are permanently preserved. Copies of these bound volumes may be purchased by members of the Society at $5 per volume and by non-members at $10 per volume. A few bound volumes still remain for the years 1923-1927, inclusive.

Welding Inspection

(Reprinted from Dec. 27, 1928, issue, *Engineering News-Record*)

The question of what is a good weld and how it may be recognized arises in nearly every discussion of the possibilities of structural welding. The trouble is not with lack of an answer, but with the wide divergence of current opinions and belief. Unfortunately, none of these various opinions is based upon sufficient facts. It is in part true that, as some welding enthusiasts charge, the engineers who oppose structural welding on the ground that it cannot be properly inspected overlook the fact that inspection in no field is perfect—that mechanical or physical determinations are at best only fragmentary evidence. But at the same time welding

engineers often forget that proof of satisfactory inspection methods lies wholly with them; at least, to date their activity in furthering methods of inspection have not been particularly evident. However, at a recent meeting of the American Welding Society, C. D. Jensen, of Lehigh University, described an interesting investigation of welding inspection, whose aims might well be emulated on a wide scale in the welding industry. Briefly, he attempted by actually examining a large series of welds to find a set of rules that would measurably cover the requirements of welding inspection. Poor welding as well as good welding was done, and all welds were inspected by a senior engineering student. Professor Jensen reported that this inspector-apprentice soon developed surprising accuracy in judging welds visually by such qualities as porosity, neatness, spatter, fusion, overlap, and size and depth. Still greater accuracy was found to result when the inspector could see the bead run, hear the arc and watch the ammeter and voltmeter. The main importance of these tests is that they demonstrated a commendable curiosity on the part of their promoters to learn how to inspect structural welding; the data on visual inspection may be considered virtually a by-product. That sight and hearing, the two senses which have been relied upon for years in inspecting riveting, are able to perform so well in weld inspection is most interesting, and justifies the hope that visual inspection may prove as dependable as in the field of riveting. After all, it should not be impossible to find an inspection method for welds that will be as satisfactory as listening for the metallic ring of the test hammer on a loose rivet head. The great requirement is for more authoritative inspection tests.

SECTION ACTIVITIES

Cleveland

On Tuesday evening, Dec. 18, 1928, the Cleveland Section of the American Welding Society met at the Engineering Rooms, Carnegie Hall, and saw a presentation of the new G. P. A. films on pipe welding.

In addition to this, a trade-mark contest was put on and great enthusiasm was shown over this feature. Prizes will be awarded to winners. Approximately 200 attended this meeting and the discussions that followed were of benefit to all.

In January the section's meeting will be devoted to the subject of welding of monel, nickel and stainless steels.

Detroit

The 1929 program of the Detroit Section is given herewith.

Jan. 16—"Resistance Welding and Welders, illustrated by slides, by H. A. Woofter, chief engineer of the Swift Electric Welder Co.

Feb. 16—"Combined Demonstration and Test Meeting in the Laboratories of the University of Detroit." This meeting will be attended by all of the local interested architects, builders, contractors, etc., who are interested in the application of welding to structural buildings.

March 20—"Effect of Torch Cutting on Strength of Structural Steel," illustrated by moving pictures, by a representative of the Linde Air Products Co.

April 17—"Replacing of Castings by Fabricated Welded Parts in the Construction of Electrical Machinery," by a representative of the Westinghouse Electric & Manufacturing Co.

May 15—"Metal and Thermit Welding," illustrated by a representative of the Metal & Thermit Corporation.

Los Angeles

The Los Angeles Section held a very interesting and instructive meeting on Dec. 19. After the usual dinner, the principal speaker of the evening was Prof. W. H. Clapp of the California Institute of Technology, who spoke on "The Metallurgy as Applied to the Welder." Professor Clapp, who is one of the foremost authorities on metallurgy, explained the effect of the crystalline structure on the chemical and physical properties of the plate and

the metal in a fusion welded joint. As expected, this was one of the best meetings of the section.

In conjunction with the Western Metal Congress to be held in Los Angeles in January, 1929, the American Welding Society will have charge of the program on the afternoon of Jan. 18. They have arranged for Prof. F. P. McKibben of the General Electric Co. to speak on "Steel Bridges"; Mr. Bruton of the Oxweld Acetylene Co., whose subject will be "Heat Treatment of Steel with the Acetylene Flame," and a speaker from the Westinghouse Electric & Manufacturing Co., whose subject will be "Replacing Castings by Building Machinery with Arc Welded Steel." About 500 delegates from 14 engineering societies will be present at this convention and the American Welding Society anticipates to bring welding before them in a forceful and instructive manner.

New York

A joint meeting of the New York Sections of the American Welding Society and the American Society of Mechanical Engineers was held in the Engineering Societies Building on Tuesday, Jan. 8. P. W. Swain, managing editor of Power, presented, with the aid of slides, a comprehensive review of some of the latest applications of welding in the power plant field, including electric machinery where the castings had been replaced by welding, welding of vessels and high pressure pipe lines. G. O. Carter presented a paper prepared by H. H. Moss, of the Linde Air Products Co., on the theory and practice of proper management and supervision of welders for important construction work, such as pipe lines and pressure vessels.

About three hundred people were in attendance.

Western New York

The December meeting of the Western New York Section was held on the 20th and was a joint meeting with the Buffalo Section of the American Society of Mechanical Engineers. J. F. Lincoln, vice-president of the Lincoln Electric Co., presented an interesting talk on "The Effect of Arc Welding on Manufacturing Processes."

EMPLOYMENT SERVICE BULLETIN

Opportunities.—The Society is glad to learn of desirable opportunities from responsible sources, announcements of which will be published wthout charge in the BULLETIN.

Services Available.—Under this heading brief announcements (not more than seventy-five words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period, names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Society's Office not later than the thirtieth of the month if publication in the following issue is desired. *ALL REPLIES should be addressed to the number indicated in each case and mailed to Society headquarters.*

Positions Vacant

V-44. Wanted. An Executive as salesman and publicity man for Welding Company. Opportunity for live wire to establish himself. Must have capital to buy interest in old established welding shop. Capital to be used for expansion.

Inspection of Structural Steel Welding*

CYRIL D. JENSEN†

WITH the advent of welding into the structural field the structural engineer is confronted with a new method of joining structural members. Before accepting this new method he wants not only to have it proved that welding is reliable but also that the inspection of it can be depended upon. Furthermore, he would like to know how to judge for himself whether or not a welded joint is what it ought to be. In an endeavor to be of assistance to the structural engineer, a series of tests was undertaken to determine ways and means of judging a weld.

These tests were conducted at Lehigh University with the assistance of Mr. E. H. Gardner, a student. Since there were no welders available, I had to assume the rôle of welder, while Mr. Gardner acted as inspector.

After considerable experimenting, three types of specimens were selected, all of which would be easy to make and test. (See Fig. 1). Twenty joints of the single-vee type, ten of the double-vee and twenty-five of the butt-tee type were made under various conditions. The butt-tee specimens were really tension pieces made by the process of interjecting a cross member between two short straps laid out as for a butt joint. The result was a test piece held together by four fillet welds, each of which was subjected to a cross shearing stress on the minimum section. Most of these fifty-five specimens were made up of structural steel straps or plates 2 in. in width and half an inch thick.

The specimens made represented both good welding and bad welding. We purposely tried to commit every sin possible in a welder's trade, endeavoring at the same time to discover methods of detecting each one. We tried high and low currents; we used wrong size wire for the current being delivered; we welded on paint and rust; we held short, long and irregular arcs; and, inadvertently, we once welded for a considerable period with a loose ground connection.

A test sheet was made up for each specimen and the following information noted: (1) Wire and current used, (2) Welder's observations concerning steadiness and length of arc, apparent fusion, and expected strength, (3) A cold inspection for quality of the deposited metal, flaws and apparent fusion, and (4) A record of the broken specimen, including strength of the specimen and notes as to actual flaws, quality of metal and fusion. (See Typical Specimen sheet Fig. 2).

As a result of these tests we feel qualified to point out a few of the essentials in dependable inspection of arc welding on structural steel. As a basis for proper inspection we naturally assume first of all a carefully prepared design, clear and definite, and with it a set of good welding specifications. Secondly, the welders on the job should be properly

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*Presented before New York Section Meeting, Dec. 11, 1928.

†Asst. Prof. of Civil Engineering, Lehigh University.

tested. With these two fundamentals as a basis, inspection is just what it should be, a check-up on materials and workmanship.

Welding wire is about the only material in which the inspector is interested. If it is purchased from a reputable company and contains the correct carbon content, the wire will probably prove satisfactory. One of the very best tests possible is to make up welded specimens suitable for breaking in a tension or compression machine using steel and wire

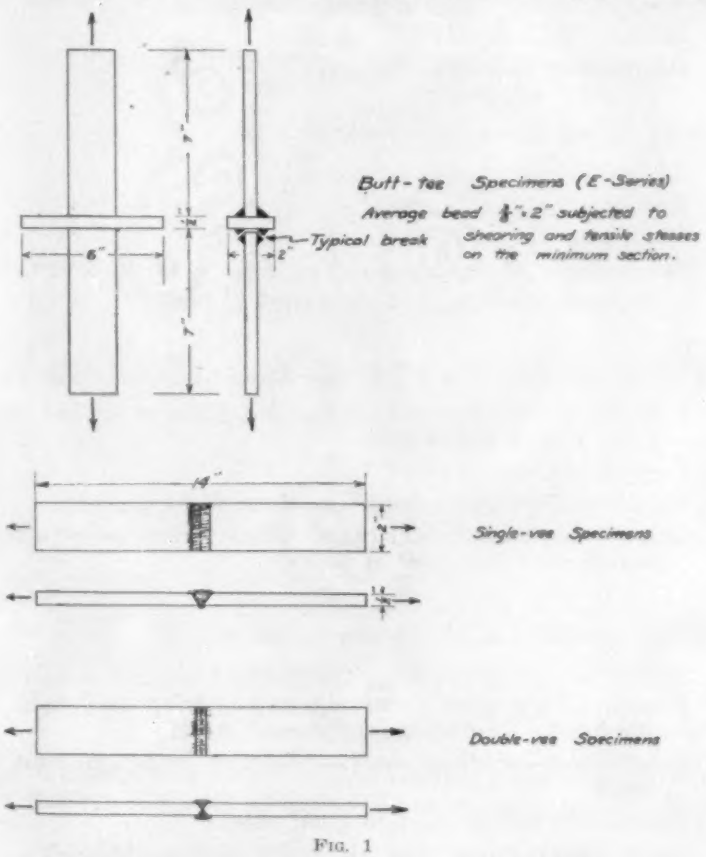

FIG. 1

obtained from the job, and to have each welder make up a few test pieces. These specimens should then be sent to a laboratory and broken. In this way a very complete and convincing test is made not only of the wire but of the welder's ability as well. Another test well adapted to practical work is to try out a wire on overhead welding. In the hands of a skilled welder good wire suitable for structural work can be welded in an overhead position without unusual splattering, whereas a poor wire will splatter incessantly. We might suggest that any wire which cannot be deposited satisfactorily overhead be barred from any structural work. Another simple test is that of freezing the wire to the work and

TYPICAL SPECIMEN—BUTT-TEE SERIES

Date: March 21, 1928

Specimen No. E-34
Wire Used 5/32 Kathode

MACHINE CHARACTERISTICS

Idling—*200A 52-54V*
Running—*155A 18V*

STRENGTH OF SPECIMEN

Ultimate unit stress—*50,000# sq. inch*
Breaking point—*43,600#*
Yield point—*31,000#*
Dimensions of specimen—*7"x2"x½" straps—6"x2"x½" Cross-member 5/16" bead—each 2" long*

WELDER'S OBSERVATIONS—*Single run on each bead*

Fusion—*Unquestioned—current hot (almost too hot after piece was warmed up)*
Length of arc—*Short*
Sound—*Sharp—regular (almost small explosions)*
Other observations—*Craters show deep penetration; should give excellent results*

COLD OBSERVATIONS—*by Gardner*

Welder—*Jensen—Grade B (neatness)*
Fusion—*Very good—scarcely any overlap and only on one bead. Rest bites into parent metal*
Splattering—*Medium am't.—Globules large, medium & small*
Color—*Tarnished steel to good steel*
Other observations (as air holes, flaws, etc.)—*No air holes; several inclusions—visible crater in one bead*

OBSERVATIONS ON BREAK

Fusion—*Good except about ½" in one corner in root*
Cause of break—*Clean break in minimum section*
Comments—*Very good silky structure*

Fig. 2

then raising the current until the rod reaches white heat and melts. The melting process in a good rod should be uniform throughout its length, whereas in an imperfect rod bubbles appear, supposedly at the flaws, previous to the melting of the whole rod. Generally speaking, the inspection of welding wire is the least of an inspector's worries.

A prerequisite of good workmanship is a properly cleaned joint; therefore one of the duties of an inspector is to see to it that all paint, rust and dirt are removed before the welding is done. Let an inspector watch

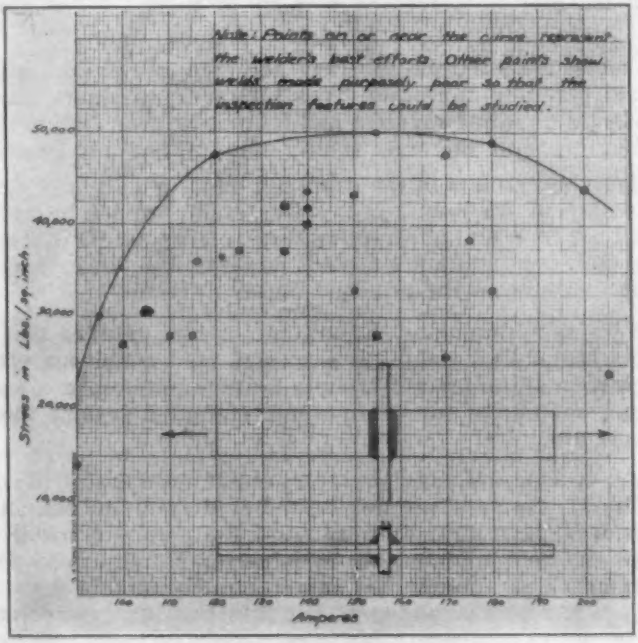
Note: Points on or near the curve represent the welder's best efforts. Other points show welds made purposely poor so that the inspection features could be studied.
50,000
40,000
30,000
20,000
10,000
Stress in Lbs./sq. inch.
Amperes

FIG. 3

a welder futilely trying to get a good bead on a painted joint and no more explanation is needed as to why specifications require the removal of paint.

Inspection of workmanship, which is, of course, the principal duty of an inspector, might be divided into three main phases: size and position of the beads, quality of the weld metal, and completeness of the fusion. The first of these, the inspection of the size and position of the beads, is merely a check up to insure that the joints are the proper size and are placed correctly. This phase of the inspection is self-evident and need not be discussed further in this paper.

Quality of the Deposited Metal.

The quality of the deposited metal is generally *easy to determine if it is good.* Perfectly laid metal is a clean steel color and just naturally

has a compact, healthy look about it. It is when the bead is burned, porous or rusted that judgment and skill in the inspection is required because some or all of these conditions can exist and often do, more or less, in commercial work without weakening the joint below good, safe limits.

A perfect weld with .18 carbon wire on structural steel will resist well over 50,000 lb./sq. in. in tension and compression and about 45,000 lb./sq. in. in shear. Since 36,000 lb./sq. in. is the approximate ultimate unit stress used in design with a factor of safety of four, certain minor imperfections may be permitted without in the least endangering the structure.

If the metal looks burned in places the inspector should examine the whole weld carefully for other flaws. Experience shows that burned places indicate unskilled welding, bad current or poor circuit conditions, all of which result in uncertain quality of metal and also erratic fusion.

Porosity or sponginess in the deposited metal is naturally detrimental to the strength of the joint. It is a flaw easily avoided by real welders and should not be tolerated except in occasional spots. Our study on the causes of porosity were not complete however, the indications seem to point to low current as the principal cause.

A weld which rusts during the cooling process indicates that too long an arc was held. This results in weakened weld metal due probably to the introduction of oxides and nitrides from the atmosphere and also to the burning out of the carbon to a much greater amount than occurs with a short arc.

There are two general solutions to imperfect condition of the deposited metal. First, if the flaws are serious, the bead should be cut out and the joint rewelded. Second, if the quality of the deposited metal does not receive the complete approval of the inspector but is not so poor as to warrant removal, permission may be given to thoroughly clean the weld and reinforce it with a second run. Let it be thoroughly understood that welders who cannot consistently lay in good metal do not belong on a structural job. Occasionally, however, a section of the work done by skilled welders may contain flaws and then the described solutions will pertain. Judgment, skill and trustworthiness are prime essentials in an inspector in order to give to the engineer and the public absolutely dependable joints and yet not cause the contractor undue burden by making him reweld satisfactory connections.

Fusion

Of the various phases of the inspection of structural steel welds, fusion is probably the one of which the engineer is most skeptical. Measuring up the beads to check size is a positive operation. The quality of the bead is, as has already been shown, easily determined by visual inspection. But fusion into the parent metal seems to the engineer the one intangible part of welding. With this in mind much of our research was spent investigating possible methods of determining the fusion.

Cold inspection, or the inspection of the completed joint, was found

by us to give very dependable results. The inspector was able after a month of practice after school hours to pick up a cold specimen and estimate its degree of fusion remarkably well. On the last thirty-five specimens every cold inspection was close to the truth with two exceptions. On one specimen, V-26, the inspector attempted to judge a weld after the bead had been milled down to give a constant cross-section, which meant the removal of his best clues. The other specimen, DV-2, had a section on one end of the bead of such appearance as to make indeterminate its fusion quality and was classified as bad, due to the fact that if it were to fail a big eccentric load would occur in the rest of the joint, causing failure at a low figure. However, it developed that both of these specimens were better than they appeared and broke under good substantial loads.

It is of importance to note that fusion was practically never overestimated. In other words, if the inspector decided that a weld was all right, it usually proved to be so, whereas a weld termed doubtful often tested out fairly well.

Cold inspection of fusion is not satisfactory for double run specimens, because the inspector does not have a chance to look at the first run, which being in the root of the weld is the important one. For this reason it is advisable never to permit double runs to be made unless specifically called for in the design, and when they are specified to inspect the first run before allowing the welder to proceed with the second course. In this way fusion can be ascertained with the same degree of reliability as in regular single bead welding.

Since our actual results showed that fusion can be judged by a cold inspection the question now is, "How shall we describe a properly fused weld?" The simplest way to describe it is to say that if a weld appears fused it probably is properly fused. The bead should seem to grow right out of the parent metal. The crater, which we shall describe later, should show proper size and depth. There should be very little overlap because overlap means incomplete fusion, misplaced metal, and because it hides from the inspector the proper penetration which may exist in the inner parts of the bead. A little experience in making, inspecting, and breaking fused and unfused specimens is by far the best teacher.

One of our indirect conclusions reached is that the procedure which we followed in our research would make an excellent method for properly training inspectors.

The crater, which is formed during the process of welding, is a real criterion of fusion both to the welder and to the inspector. We might explain for the benefit of those not intimately acquainted with welding that the crater is caused by the force of the molten metal of the electrode striking the molten parent metal. Hence the crater moves with the electrode and is visible at the end of each run during the process of renewing the electrode. As the welder carries on with the joint he fills up the crater of the previous run. Thus the only crater visible on the cold specimen is the one at the very end of the joint. It is important that the welder should leave this final crater in its natural state for inspection purposes. If the inspector is present during the process of

welding he can examine each crater left during the process of changing electrodes; otherwise he can examine only the final one.

Size, shape, and penetration of the crater are the features noted by the inspector. Under ideal conditions the crater will be a neat circular affair penetrating down into the parent metal a trifle. Then the statement can be safely made that the joint is properly fused at that end of the bead. But a good crater does not necessarily certify fusion at the starting end; and that happens to be the end most likely to be unfused. When a weld is first begun the plates are cold and fusion is consequently in doubt for a distance of a quarter of an inch or more. Then as the plates warm up welding is made easier and fusion more certain. For this reason an inspector should not get into the habit of glancing at the crater only.

The crater is also indicative of the current used. If it is small relative to the size of the bead and plates it indicates too low a current; and inversely, a very large elongated crater indicates too high a current and a wild flame. Thus we conclude that the "crater test" is a valuable guide revealing excessive variations of current and a good approximation of the penetration obtained.

Neatness of bead is in itself a requirement for a first class weld; however, it is not an absolute indication of fusion. It is possible to produce a neat appearing weld in spite of poor current conditions or too long an arc; but a close examination of such a weld would show that the bead were merely lying on the parent metal rather than fused into it.

Splattering, or the depositing of globules of weld metal alongside the joint, seems to have only an indirect connection with fusion. Some of our poorest specimens showed no splattering at all while some well fused, fairly strong specimens showed a considerable amount of it. Although we did not make an extensive study of splattering we noticed that it was most pronounced under poor welding conditions such as poor circuit, poor wire, too heavy current for the wire, or too long an arc. Any one of these poor welding conditions is very apt to affect either the quality of the deposited metal or the perfection of the fusion. Hence the inspector should view with disfavor any joint showing excessive splattering.

Sound of the arc was found to be a very important item in proper inspection. As long as the welder is proceeding over good clean metal with a good current and a short steady arc, it will be advertised to all within hearing by a sharp rapid regular sputtering or crackling sound. But the moment thick rust or paint is encountered, out goes the arc. The lazy welder may attempt to continue the work without cleaning the surfaces. Several things will occur. The sputtering will be intermittent due to short periods of broken arc. Splattering will probably occur in large globules. Neatness will suffer. And if a person were watching the meters he would see wide fluctuations from moments of no current at all to full current due to freezing of the wire to the work. All in all there are many telltale evidences of that type of poor work. A hissing sound is caused by holding too long an arc; and of course poorly deposited metal and doubtful fusion will be the results. A careless or tired welder will often hold an unsteady arc which will be heard as an

intermittent crackling and hissing. A cold inspection of his work would probably show some large globules of weld metal alongside the bead, irregularity of texture, porosity in spots, and a covering of rust over the bead. Due to this close association between sound of the arc and the actual results it is our contention that a skilled inspector could practically pass on a weld without even looking at it, provided he could listen to the work as it progressed. While we do not advocate the use of sound as the principal means of inspection, we do feel that its mastery by an inspector is a decided asset.

Hand in hand with judging the steadiness and length of welding arc by listening to the sound produced is that of observing the actions of the ammeter and the voltmeter. No human being can hold an absolutely steady arc but there are acceptable variations. A skilled welder holding a short steady arc will keep the voltmeter needle hovering close to eighteen or twenty volts. The ammeter being more sensitive will show wider fluctuations but will show a definite range of current.

Current

Perhaps the most important single phase in an inspector's line of duty is to see that the welder uses the proper current for the particular job he is on. At present the designer cannot name an exact current to be used, but from tables based upon thickness of plates to be joined can designate the range of current and the size of wire. We found quite decidedly that the amount of current used determines largely the strength of a weld. (Figure 3 shows a typical stress—ampere curve). For the half inch specimens which were used in our research the peak in the stress-ampere curve was rather flat and was between 140 and 170 amperes, depending on the heat conducting ability of the work. For instance, in joining two straps in a single-vee butt joint a relatively low current proved best. A high current caused the plates to become red hot for a short distance on each side of the joint. But in making a lap weld there is really one inch thickness of plate on the one side helping to absorb the heat. In this case a higher current is required to insure penetration of the bead into the plates.

Present information on the subject of proper current values for the various structural connections is lacking. We are dependent on the skill of the welder in adjusting his own machine. This is an important "human element" problem which will be overcome in time. However, since proper adjustment of the current is a part of the training of every real arc welder we should not consider this lack of information a drawback to arc welding of structural joints but rather as an opening for further improvement.

Conclusions

The direct conclusions obtained from our research are as follows:

(1) A welder has a very good estimate of the strength of his own welds; and if he could be depended upon absolutely inspection would hardly be necessary.

(2) An inspector thoroughly trained in welding can watch it in progress and can arrive at an estimate of its strength as well as can the welder.

(3) A skilled inspector can listen to welding in progress and predict to a fair degree the quality of the weld. His estimate, however, would only be in one of three classes—good, poor, or doubtful.

(4) An inspector can watch the ammeter and voltmeter and knowing the size of wire used and the size and kind of joint should be able to predict the qualities of the weld.

(5) A properly trained inspector can by scrutinizing a cold weld and by correctly interpreting such features as quality of the deposited metal, porosity, neatness, splattering, degree of rust on the weld, apparent fusion, overlap, size shape and depth of the crater, reach conclusions very dependable indeed.

Producing All-Steel Automobile Bodies with Oxy-Acetylene

J. W. MEADOWCROFT†

THE following statistics are offered to designate the very important part the oxy-acetylene welding process plays in the production of ALL-STEEL AUTOMOBILE BODIES.

In this case we have attempted to make direct comparison of the total per cent of money expended in the purchase of oxygen in comparison with the company's yearly business. Had we attempted to use the total cost of welding material, including carbide, dissolved acetylene, filler rods, welding goggles, pressure hose, new equipment, replacement parts, maintenance, etc., our percentage would, of course, be considerably higher.

Inasmuch as we are attempting to show a yearly comparison and as all oxygen consumed in our plant is used exclusively in oxy-acetylene welding or cutting, our yearly comparisons will be in perfect order to show the status of this welding process in our particular line.

In 1913—.51 per cent of total business was used in purchase of oxygen.
In 1914—.5 per cent
In 1918—.3 per cent
In 1919—.31 per cent
In 1923—.34 per cent
In 1924—.3 per cent
In 1927—.23 per cent

From the above figures you will note a slight decline in the oxy-acetylene process in our particular line.

While the decline is very slight on the total consumption comparison, the actual percentage of reduction on the final plant production amounts to approximately 28 per cent. The reduction of 28 per cent in the use of oxy-acetylene in the production departments and the maintaining of the total plant reduction at approximately 7/100 of 1 per cent would indicate that the consumption by other mediums must have existed.

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†Assistant works manager, E. G. Budd Manufacturing Co.

The advent of electric flash welding in sheet steel has been a great medium in the elimination of oxy-acetylene welding, but the tremendous stress placed on design in the past five years has been the governing factor.

We will attempt to guide you through the various departments of our plant citing, at the same time, the items that have been responsible for the maintaining of such an extremely slight decline in the total use of oxy-acetylene welding.

The first department we enter is the machine and new die shops. Here we find an exceptionally large amount of oxygen and acetylene being

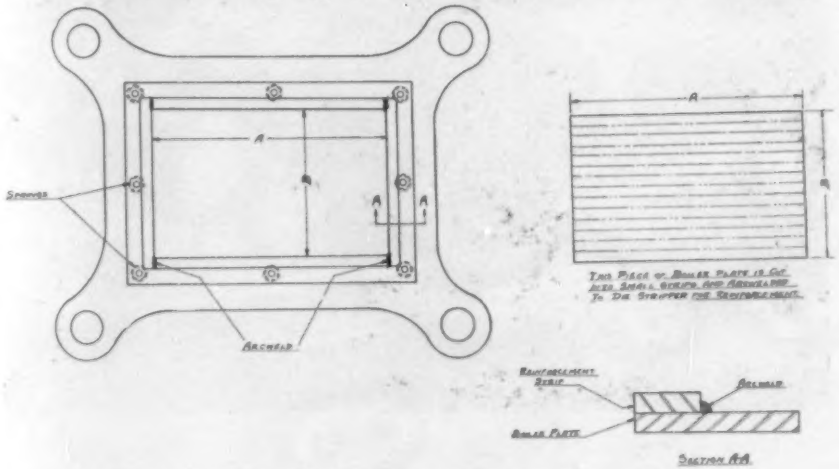

FIG. 1. STANDARD METHOD OF PRODUCING DIE STRIPPER PLATES

used in the rough, cutting of bar steel and boiler plate for new die parts. At this point we are furnishing sketch, Fig. 1, showing the important part the cutting torch plays in the production of new die stripper plates. The section shown cut from the center of the mainplate is cut over its "A" length and arc welded in place as a reinforcement along the working edge of the stripper. The functions of the stripper plate is to automatically knock the stamping from the punch on its upward stroke after formation of the stamping.

The savings involved in producing a die part by this method amounts to approximately $115.00 in direct labor.

The next department we enter is the Die Maintenance shop where all die maintenance possible is accomplished by the use of Oxy-Acetylene. The items chiefly involved are the repairs required on steel inserts where the forming edges have worn beyond their inspection limits. We find these inserts being removed from the dies and delivered to the welding shop with instructions to reweld with various welding rods from 0.65 carbon steel to drillrod and in many cases Stellite is requested, the amount of resistance to abrasion required being the governing factor of the material to be used.

In Fig. No. 2 we bring to your attention the maintenance possible in the use of Oxy-Acetylene on the larger Cast Iron Die sections. The total weight of the casting as it was delivered to the welding shop was 7349 lb. In twenty-four hours it was returned to the machine shop, the total weight being 7509 lb.

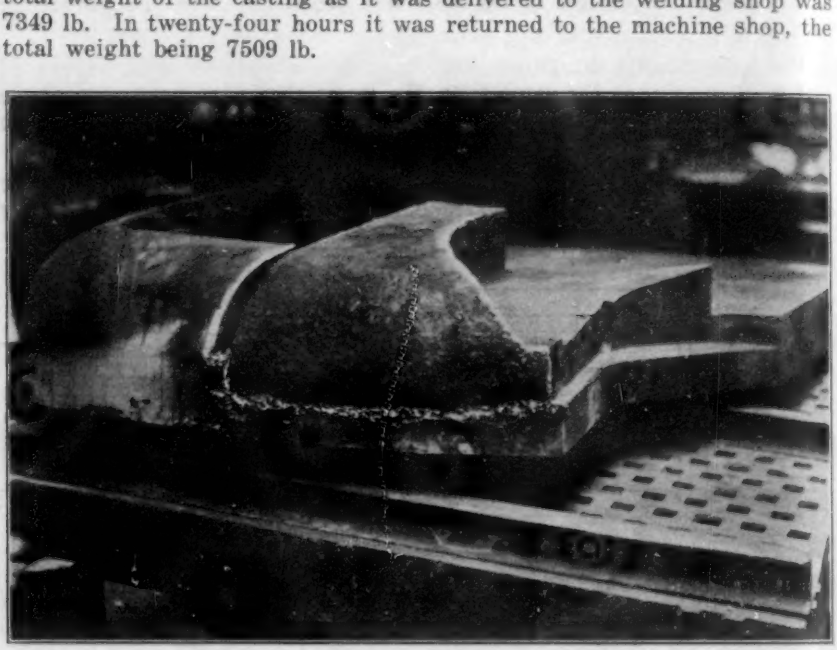

FIG. 2. WELDING IN THE MAINTENANCE OF CAST IRON DIE SECTIONS

The detail of the repair follows:

Added material	—160 lb. Cast Rods
Cast Iron Flux	— 4 lb.
Sheet Asbestos	— 25 lb.
Total Preheater time	— 12 hrs. (20 buzzer burners)
Total Labor (2) men	— 32 hrs.
Savings involved	3 weeks' time and 75 per cent of cost of new finished casting.

The next department we enter is the Main Press Shop where the dies manufactured in the Machine Shop are in operation. Here we find a portable welding outfit in operation applying patches in small Cast Iron sections with Tobin Bronze and brazing locating Gauge Pins in place without removing the die from the Press.

Our next department is the Maintenance Department. This department is directly responsible for the continuous operation of the entire plant equipment. In Figs. 3 and 4 an idea is offered of the constant break downs occurring and the immediate repairs required. In Fig. 3 a cast iron press gear is shown with a total of nine teeth replaced. A gear broken to the extent of the one shown is immediately removed from the machine and replaced with a repaired gear from stock. The

broken gear is then sent to the welding Shop, repairs made in the usual manner, allowed to cool down sufficiently for machining, machined and returned to stock. This type repair is usually accomplished in thirty-six hours. A gear of this type with one or two teeth to be replaced would not be removed from the machine. A series of studs would be inserted to represent the missing tooth, and by the aid of carbon blocks the studs would be brazed in place and the desired material added between the studs to form a complete new tooth. The filler material would be

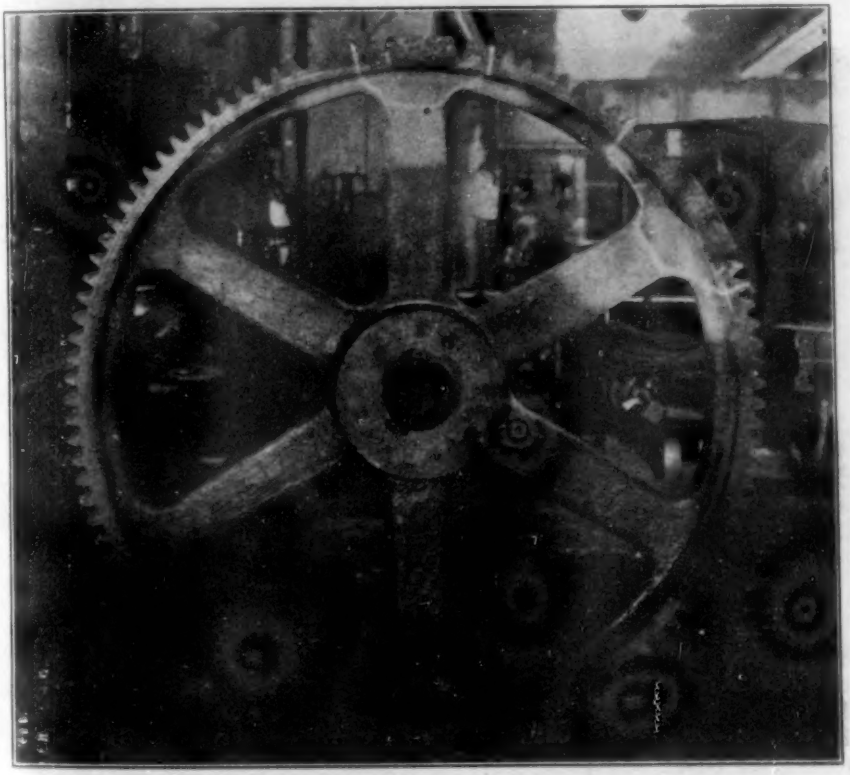

FIG. 3. WELDING BROKEN GEAR TEETH

Manganese Bronze used with special flux of our own manufacture. The amount of savings involved in repairs of this nature and savings in time amount to about 300 per cent.

In Fig. 4 the completed repair is shown on a Cast Iron Press Bearing Bracket. This repair was accomplished in seven hours by two men and twelve hours allowed for cooling. The outer bracket of the bearing is of babbit and was completely saved by keeping it cooled down with wet asbestos. After cooling, the bracket was painted and returned to its former position on the machine. Its alignment was perfect.

At this point we feel we should offer a glimpse of a welding repair shop. This shop is located at a point of easy access to both the Machine and Maintenance Departments. Fig. 5 offers such a view. The overhead equipment consists of a ten ton Electric Crane and exceptionally well arranged skylight ventilators. The bench shown in the circle is an especially designed pre-heater with forty-eight City Gas Buzzer Burners so arranged that the largest or smallest repair may be handled in a most efficient manner, the welding operation being performed while the preheater is still in operation.

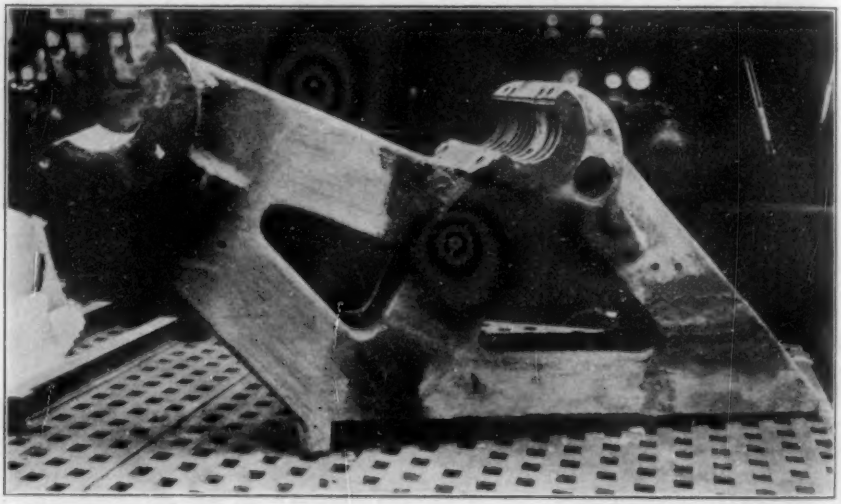

FIG. 4. WELDING CAST IRON PRESS BEARING BUCKET

In passing on to our Electrical Shop we find an Oxy-Acetylene Welder busily engaged in making immediate repairs to motor parts, etc., such items as split motor housings that ordinarily have a purchase cost of $15.00 when new are repaired at a total cost of $3.50. The Aluminum End Housing of hand electric drills that ordinarily cost $3.75 are repaired for $0.30.

We then enter the Main Tool Room where all small tools originate. We find here a welder busily engaged in making repairs to Copper Electric Spot Welding Dies and numerous other small tools. An example of the savings involved on Copper Spot Welding Dies is designated by the actual cost of a new die amounting to $0.34 and the repair cost being $0.13. Where 950 Electric Spot Welders are in continual use on production a tremendous saving exists in the reclaiming of large amounts each of over 200 different designs.

At this point a question may arise as to the conductivity of the welded copper. We use only high conductivity copper rod, coated with our own special flux, for filler material and we are quoting here a conductivity

test made at the University of Pennsylvania, May 26, 1925. The test follows:

No. 1—6 in. of ⅝ Rd. Hard Drawn Copper	97.7%
No. 2—2—3 in. pcs. ⅝ Rd. Hard Drawn Copper Welded and Forged in Center	98.7%
No. 3—2—3 in. pcs. ⅝ Rd. Hard Drawn Copper Welded Not Forged in Center	98.2%

This test was made on a Thomson Standard Double Bridge in the Electrical Testing Laboratories of the Moore School of Electrical

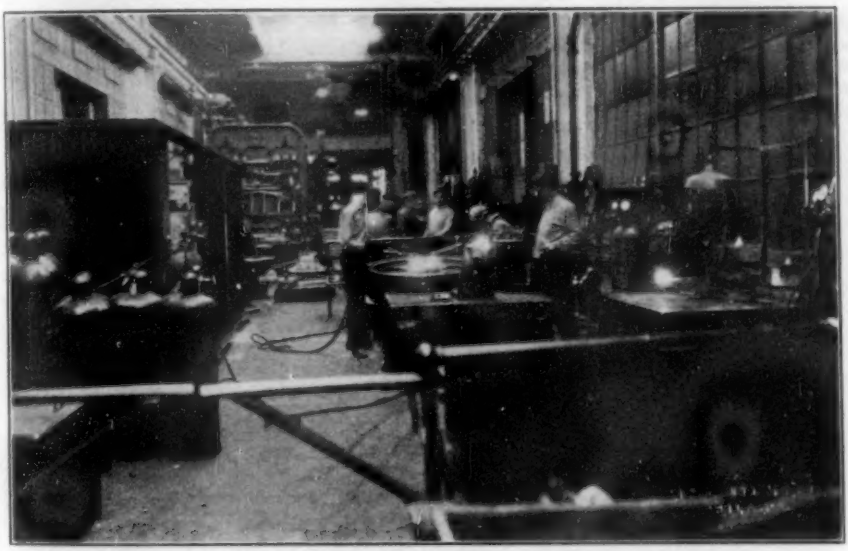

FIG. 5. GENERAL REVIEW OF WELDING REPAIR SHOP

Engineering, University of Pennsylvania. The test was run in accordance with the standard methods of the American Institute of Electrical Engineers.

The welded pieces in this case are superior to the solid stock, but a variation in the grade of material may have had some bearing as each coupon was cut from a different stock bar.

In entering the Production Department we find comparatively few Oxy-acetylene Welders at work today in the various unit departments in comparison with the amount noticeable ten years ago. While flash welding and design along with the greater perfected means of producing one piece stampings have been instrumental in reducing the amount of this process used in our unit departments. Electric seam welding by roller and continuous spot welding have also aided considerably.

In our final body assembly department we find the greatest advantages of this process. Our methods of production require that the body be produced in units, enter a final assembly jig and be removed as one unit.

The quickest and best means possible in this case is to weld all vital parts in perfect alignment by Oxy-acetylene. Its application is very quick and positive and all parts are easily accessible by this method. The parts not vital to alignment are allowed to pass from the assembly jig unwelded and are later welded on the finishing line conveyors. Correct supervision is essential at all times where the supply of work to the welder depends on the speed of the conveyor.

The following quotation is abstracted from an inter-department letter urging the supervisors to produce from the material used, the maximum production.

"The welding operators on conveyor No. 9, column 62. Total gas cost at this point amounts to $0.92 per hour by two men or $0.46 each man. The total time required for each man to complete this operation is one minute and ten seconds. The conveyor is traveling at a speed of 36 pieces per hour or one piece each one minute and forty seconds. The operator hurries and completes his welding and stands with lit torch for the remaining 30 seconds until the next piece could be worked on. Please note the amount of money that can be saved from the following:

The present cost of gases is $0.46 per hour each operator. A smaller tip consuming $0.179 worth of gases it is found completes this operation in one minute and 30 seconds and produces a considerably neater job.

The money saving in this case is $0.28 per hour per man or a total of $5.60 per ten hours for two men."

The following figures are set up from our records in the past eight years showing the strides we have made in offsetting a very great reduction in the use of Oxy-acetylene had we depended only on our final production of ALL-STEEL AUTOMOBILE BODIES and UNITS.

The percentage of total Oxygen consumed in all departments except actual production departments follows:

1920	5.7%
1925	13. %
1927	20. %

In conclusion, we feel that if we are able to extend the same efforts along the same line of progress for the next five years, we should show a considerable gain in our total, and our percentage as compared with 1927 will be comparatively higher.

The Welding of Aluminum and Its Alloys*

By W. A. DUNLAP†

Introduction

THE purpose of this paper is to supply general information on the welding of aluminum and its alloys. An extended academic discussion of the problem has not been attempted. When preparing this paper, the writer had in mind primarily the practical welder. If the information contained herein enables the man with the torch to turn out good welds in aluminum consistently, the aim of the writer will have been realized.

Fusion Welding

The term "fusion" is thought to be much more appropriate than "autogeneous," which is sometimes incorrectly used for this type of welding. There are two general classes of fusion welding: the first, arc welding, which is most commonly used in steel work, has not been sufficiently developed for use with aluminum to permit using this process as a commercial application. The second class, torch or gas welding, is used extensively in the aluminum industry.

Among the methods which are employed for joining aluminum or its alloys, none is more generally satisfactory than fusion welding with the oxy-hydrogen or oxy-acetylene torch. In the hands of an experienced aluminum welder the process is simple and rapid, and it can be applied to metal of all thicknesses. The resultant joint is not unsightly, and if necessary the weld can be finished off in such a way that it is impossible to detect where the joint exists.

The same type of weld, that is, butt, lap, tee, fillet, etc., is made in aluminum as in any other metal. Some training will be necessary before a welder can turn out consistently reliable results with aluminum. This metal has distinct characteristics of its own which involve a somewhat different technique from that required for steel, cast iron and other metals. However, this special technique is by no means difficult to acquire, for in point of fact, aluminum is one of the most readily weldable of all metals.

Torch welding is applicable both to the manufacture of articles from sheet aluminum and to the repair of aluminum alloy casting. In these two applications, the methods of working are generally the same, though the difference in physical properties may involve slight modifications. Aluminum alloy castings being more brittle than the pure aluminum sheet, the danger of cracking due to expansion and contraction effects is more serious; on the other hand, pure aluminum sheets are normally much thinner than aluminum castings and hence require a more delicate

*Presented before Pittsburgh Section, A. W. S., Nov. 21.

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handling of the torch. For both classes of material certain precautions are necessary if reliable welds are to be obtained. In the following paragraphs emphasis will be placed on the principal points to be observed in the welding of aluminum and its alloys.

Welding Apparatus

The apparatus required for the torch welding of aluminum is not different from that required for welding other metals, and consists essentially of a supply of oxygen and hydrogen or acetylene, with reducing valves and safety valves, torches and a series of tips. The oxygen, hydrogen and acetylene is usually obtained from cylinders of compressed gas.

The selection of the correct size of torch tip for any particular work is practically a matter of experience. The tables given are merely a guide for the inexperienced welder, since the size of the tip must depend greatly upon the shape and size of the object to be welded, as well as upon the thickness. The welding of a large tank of aluminum will require a larger tip than the welding of a small piece of bar of equal thickness, because the larger article has a much larger capacity for heat and a larger radiating surface. Much of the heat applied to the edges of the metal to be welded escapes by conduction to remote parts of the object, where it is absorbed in raising the temperature, and part is radiated away to the air. The tip must be of sufficient size to melt the edges in spite of this continuous draining away of heat. The size of the tip will also depend to some extent upon the skill of the welder, a quick worker will be able to use a large tip which in the hands of a slower and less experienced man, would result in overheating and the formation of holes. Table 1 gives the approximate size of tip and the gas pressure to be used when welding aluminum.

TABLE I

Oxy-Hydrogen

Metal Thickness, B. & S. Gauge	Size of Orifice in Tip	Oxygen Pressure	Hydrogen Pressure
20 Ga. to 18 Ga.	0.062 in.	1 lb.	2 lbs.
16 Ga. to 14 Ga.	0.078 in.	1 lb.	2 lbs.
12 Ga. to 10 Ga.	0.093 in.	2 lbs.	4 lbs.
1/8 in. to 1/4 in.	0.109 in.	4 lbs.	8 lbs.
5/16 in. to 3/8 in.	0.125 in.	8 lbs.	12 lbs.

Oxy-Acetylene

Metal Thickness	No. Tip	Size of Orifice in Tip	Oxygen Pressure	Acetylene Pressure
24 Ga. to 18 Ga.	1	0.031 in.	1 lb.	2 lbs.
16 Ga. to 14 Ga.	2	0.042 in.	1 lb.	2 lbs.
12 Ga. to 10 Ga.	3	0.051 in.	8 lbs.	6 lbs.
1/8 in. to 3/16 in.	4	0.062 in.	12 lbs.	8 lbs.
1/4 in.	5	0.074 in.	20 lbs.	8 lbs.
5/16 in.	6	0.084 in.	25 lbs.	8 lbs.
3/8 in. to 5/8 in.	7	0.095 in.	25 lbs.	8 lbs.

Flame

It is preferable to use an oxy-hydrogen flame whenever it will supply sufficient heat. The oxy-hydrogen flame produces a cleaner and more satisfactory joint and supplies sufficient heat for welding metal up to 3/8

inches in thickness. As indicated in the table, a larger tip is used for hydrogen than for acetylene on a given gage of sheet.

Whether using hydrogen or acetylene, the torch should be carefully adjusted to show a neutral flame, as this gives the best speed and economy, as well as a cleaner and sounder weld. The oxy-hydrogen flame is neutral when the volumes of the two gases issuing from the tip of the torch are just balanced. If there is an excess of oxygen, the flame will be rather small and will have a very short small cone at the tip of the

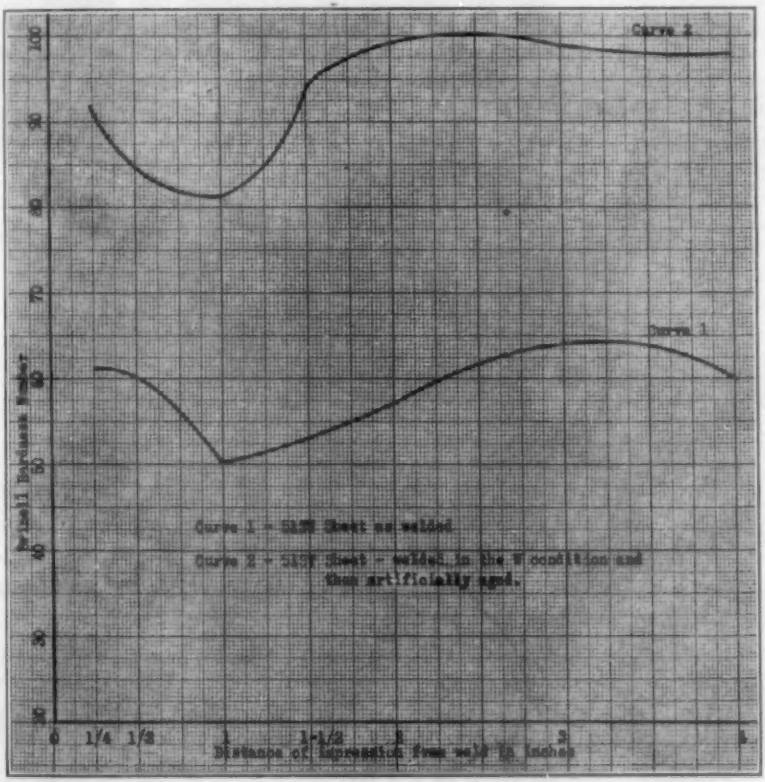


FIG. 1

torch. With an excess of hydrogen the flame is long and ragged, and there is no defined cone at the center. The neutral flame, in which the mixture of the two gases is just right, has a well defined jet or blue cone in the center of the large flame.

Puddling Method of Welding

All aluminum is coated with a thin film of aluminum oxide which prevents the easy coalescing of the two surfaces of molten metal. The production of a sound weld in aluminum necessitates the removal of this oxide film. This obstructing film can be broken up mechanically by

manipulation of the welding wire. In breaking up the oxide film by this process, which is known as "puddling," the welder, as he proceeds, stirs continuously the molten bath with the welding stick or an iron wire. In this way he breaks up the oxide film and allows the metal to coalesce, and at the same time he scrapes the oxide to the surface. This method is not a satisfactory one, because it is difficult to completely remove the oxide from the bath by puddling, and there is considerable risk of oxide inclusions in the solidified metal making an unsound weld. It would be too strong to state that it would be impossible to obtain a satisfactory weld by this method, but the quality of the weld depends so greatly upon the dexterity of the welder that it would be unsafe to rely upon the process for important work where the strength required is considerable. Apart from this, the method is slow, and therefore costly in gas and labor.

Flux Method of Welding

The most effective method of removing the oxide is by the use of a flux which has the ability to dissolve the aluminum oxide so that coales-

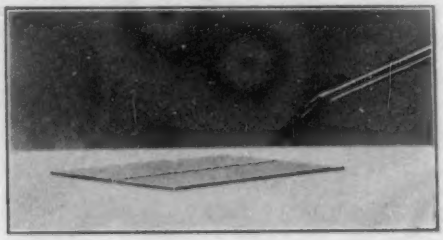


FIG. 2. BLOWPIPE HEAD SHOULD BE HELD AT AN ANGLE OF 30 DEGREES TO THE SHEET SURFACE

cence may occur. A satisfactory flux for the welding of aluminum must have the following characteristics:

(1) It must melt at a suitable temperature below the melting point of aluminum.

(2) When molten, it must have the ability to dissolve aluminum oxide and do it very quickly.

(3) The dissolving capacity of the flux must be sufficient to take care of all the oxide which might happen to be present.

(4) The molten flux, with the oxide dissolved in it, must have a specific gravity less than that of the molten aluminum, and the difference must be sufficient so that the flux will quickly and readily come to the surface of the molten metal, thus removing the oxide from the weld.

(5) The flux must be stable under the temperatures employed.

(6) It must not deteriorate with time, nor must it be too deliquescent.

Fluxes filling the above requirements are prepared by a number of reputable manufacturers.

A satisfactory way to use the flux is to moisten it with water to the consistency of a thin paste. A very convenient flux container is made from a piece of three inch pipe. An aluminum, brass or glass flux container should be used. Iron is likely to cause contamination by chemical reaction with the flux. A day's supply of the flux and water solution should be made up each morning. If any of the solution is left in the container over night, it should be thoroughly broken up and stirred next morning, as it tends to lump and crystallize upon standing. The flux is made slightly hygroscopic to prevent it from drying out and blowing off the seam ahead of the welding torch. Due to this slightly hygroscopic condition, the dry flux, if left exposed to the atmosphere, may deteriorate. The dry flux is quite stable if the container is kept closed.

If a welding wire is used, the wire is dipped into the flux solution, or if no filler metal is used the flux is applied to the joint by means of a

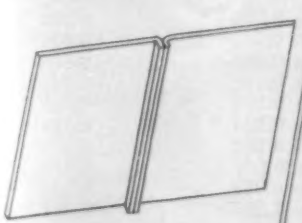


FIG. 3. LIGHT SHEET FLANGED THE THICKNESS OF SHEET

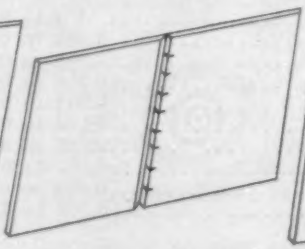


FIG. 4. LIGHT SHEET PREPARED FOR WELDING. ONE EDGE NOTCHED, THE OTHER BEVELED AT 45 DEG.

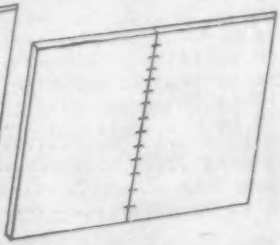


FIG. 5. LIGHT PLATE PREPARED FOR WELDING BY NOTCHING EDGES

small paint brush. In this manner, the flux is supplied to the weld where, when, and in the quantities required.

Welding Rod

Of utmost importance is the selection of the proper welding metal. The use of a welding rod or feeding stick is necessary with all but the thinnest sheet. Commercially pure aluminum (2S) and aluminum-manganese alloy (3S) should be welded with a pure aluminum welding stick. For welding the strong aluminum alloys (17S, 25S and 51S) a five per cent silicon welding stick is recommended. However, a welding stick of the same composition as the alloy to be welded will give perfectly satisfactory results if proper allowance may be and is made for expansion and contraction. The silicon welding alloy has a relatively slight solidification contraction and on account of its having a lower melting point than the base metal, it remains molten longer and fills in the voids caused by the solidification contraction of the base metal in the same way that a gate fills in the voids of a casting. This means that the stresses due to contraction which might otherwise cause incipient cracking in the base metal shift their effects to the metal supplied in welding. This metal which is noteworthy for its freedom from hot shortness, which probably means ductility at temperatures just under the melting point, as well as strength at these temperatures, will

stand the stresses without the development of cracks. There is necessity or caution in one respect when using a five per cent silicon alloy welding stick. If the welded articles are to be subjected to a high temperature or "solution" heat treatment after welding, it will be necessary to recognize the fact that this amount of silicon lowers the safe temperature to which some of the strong alloys may be heat treated. Whether the original material is 51S, 25S, 17S or aluminum-copper alloy, it will be safe to use heat treating temperatures up to about 940 degrees Fahrenheit even when the five per cent silicon alloy is used for welding.

The sizes of welding wire recommended for aluminum and aluminum alloys are given in Table II.

TABLE II

Thickness to Be Welded B. & S. Ga.	Inches	Welding Wire Diam., Inches
Up to 18	Up to 0.040	0.080
18 to 16	0.064 to 0.051	0.092
16 to 14	0.051 to 0.064	0.104
14 to 12	0.064 to 0.081	0.116
12 to 10	0.081 to 0.102	0.128
10 to 8	0.102 to 0.128	0.144
8 to 6	0.128 to 0.162	0.160
6 to 4	0.162 to 0.204	0.176
4 to 2	0.204 to 0.258	0.192
2 to 00	0.258 to 0.365	0.212

Preparation of the Edges

Light aluminum sheet (0.050 and lighter) is usually flanged in preparation for welding as in Fig. 3. The flange should be about the same height as the thickness of the sheet or just a little higher. The joint is made by holding the two upstanding edges together and melting these down. For such work as this no welding wire is required. Beveling is unnecessary for light sheet.

Heavier sheet can be beveled as is usual with steel plate. However, it is easier to obtain full penetration by notching the sheet as shown in Figs. 4 and 5. The edges of the sheet are cut through the entire thickness, the notches being about as deep as the thickness of the material, and about one-fourth inch apart. In welding, the edges are butted close together. By preparing the edges in this manner, the flux works down for the full thickness of the material, and considerable welding rod is saved. There is less chance of "burning through" and the notches act also as little expansion joints, minimizing local distortion.

Particular care is needed when preparing the broken edges of an aluminum casting for welding, since these are occasionally porous and may contain absorbed oils, which, if not removed, will cause blow-holes in the weld. A good plan is to heat the edges before beginning to weld, when the absorbed grease will be sweated out and can be wiped off. Perhaps the best cleaning mediums are a wire scratch brush and some gasoline. Not only the edges to be welded, but also the adjacent surfaces above and below should be cleaned with the scratch brush and washed in gasoline.

Preheating

Aluminum sheet 3/8 inch thick and thicker should be preheated. Preheating will limit the consumption of oxygen and acetylene to that required for the actual melting of the seam. Furthermore, preheating will tend to prevent distortion. If the base metal for some distance on either side of the seam is maintained at a temperature not very greatly below the melting-point, then, when the torch is applied to any one point, the additional expansion of this will be small and is unlikely to cause distortion. However, local preheating must be applied with care, especially in castings, for the presence of strengthening ribs, or other devices which tend to prevent the free expansion of the parts, can possibly lead to fractures during the preheating itself.

The preheating of the whole object is not always possible, and in such cases local preheating must be resorted to. When total preheating is adopted there is little danger of expansion cracks, provided the heating is done slowly and uniformly, and that the object is well protected from drafts during welding.

A broken aluminum crankcase may be taken as a typical example of a job requiring preheating. The crank case is thoroughly cleaned and the broken pieces clamped in place. The crank case is placed in such a position that the crack to be welded is in a horizontal plane. A furnace is built about the casting, using fire brick laid snugly without mortar. A moderate amount of charcoal is placed in the furnace banking it against the walls. The exact amount of charcoal depends upon the size of the crank case. Enough should be used to bring the casting to the proper temperature in about thirty minutes. It is important that the fire be kept under control and the casting heated slowly and only to a medium temperature. The upper limit should be 850 deg. Fahr. The two following methods are given for determining the correct temperature for welding.

(1) Cold aluminum gives a metallic sound which becomes duller as the temperature is raised. At the temperature required for welding, there is no longer a metallic ring.

(2) Heat the casting no more than required to leave a char mark on it when rubbed with a pine stick. Aluminum in this condition is extremely fragile and must be handled with great care.

As a welder becomes experienced in handling aluminum, he will at times be able to use a low temperature oil or gas burner for preheating. In this case the preheating is done locally along the crack, just ahead of the welding flame, so that the welding heat will not bring on too sudden a rise in temperature and cause further cracking.

Supporting the Work

The work should be so supported that the under side of the weld is free, in order that the added thickness of metal in the weld may form a slight bulge on the under surface which can afterwards be dressed down if desired. A strip of asbestos which has been previously heated to drive out the moisture makes an excellent backing material for the welding of aluminum.

There is no danger of metal falling away during the welding, even when the underside is unsupported, unless the weld is excessively wide or the thickness dealt with is very large, or melting carried too far.

At times it is advantageous to use jigs to hold the edges in proper relative positions. Where work is done in production, careful study of the matter of design and construction of jigs and fixtures will well repay the effort and expense involved.

Expansion and Contraction

As heat is applied to aluminum its temperature increases and the metal expands. This fact is very obvious, but it is not sufficient to merely recognize and accept that fact and then dismisss it from further thought. It is important to analyze this phenomenon in detail with the object of applying the mechanisms concerned to the actual practice of welding.

The coefficient of expansion is the increase in unit length per degree centigrade increase in metal temperature. The coefficient of expansion increases with increase in temperature and differs for various metals. The coefficient of expansion of aluminum is about twice as great as that of iron and one-half as much again as that of copper. That expansion is a definite thing, and that it is not some abstract property which functions only theoretically is shown by the fact that should bars of aluminum, copper and iron, each 1000 ft. long, be heated up to 100 deg. cent., the iron bar will increase in length about 13 in., the copper bar about 20 in., and the aluminum bar about 27 in. In addition to the volumetric or dimensional change due to expansion, there is also the irresistible nature of the force which produces this growth. If a bar of metal of proper length to just fit in between two fixed brackets is heated, the bar will buckle due to its tendency to increase in length. Expansion operates in all directions. If the bar is hindered from increasing its length, it will not assume its new required volume by merely becoming thicker like rubber. Of course the bar will become thicker due to expansion, but it will also increase in length. The forces which produce this expansion are atomic in nature and will not be denied. Therefore as the metal heats and expands, we must deal both with the new dimensions involved and also with the tremendous forces which produce this growth. The reverse action takes place as the metal cools and contracts.

Aluminum, copper and iron melt at different temperatures. Aluminum melts at about 657 deg. Cent., copper at 1083 deg. Cent. and iron at about 1530 deg. Cent. Should each of these three bars be heated to their respective melting points, the aluminum will be the shortest of the three. Therefore, not merely the coefficient of expansion must be considered but also the temperature change, because the product of these two determines the total expansion.

In the above cases it was assumed that the metal was heated uniformly. In fusion welding, however, the heating is accomplished by applying a torch to one area, therefore the object is not heated uniformly. If a torch is applied to the center of a sheet of aluminum, the sheet will

be heated at that point and the metal all around the central area will also be heated, but to a decreasing extent moving farther away from the point of heat application. The metal will tend to expand accordingly, the center growing more than the concentric area farther away. This tendency to grow can be accomplished only by a buckle forming in the sheet. If the sheet is perfectly flat and at a uniform temperature before heat is applied, the buckle will rise toward the flame. The sheet will not buckle downward away from the flame and this is due to the fact that the surface nearest the flame is the hottest. A temperature gradient is set up through the thickness of the sheet and since the top surface must expand more than the bottom due to this gradient the sheet will buckle upward toward the flame. This is a very important detail in connection with welding sheet because some of the major troubles and difficulties with which a welder is concerned are due to warping and buckling of the sheets. The above are the underlying principles governing buckling and warping.

After completion of the weld all the heat which has been put into the work must be dissipated. When the metal cools the processes described above will be reversed; in other words, where there has been expansion there will now be contraction and the net volume changes and forces involved will theoretically be equal in amount, though opposite in direction. Care must therefore be exercised in practice that the net result will be zero. If the dimensions cannot come back to what they were originally the work will be buckled and the weld will be severely strained. The weld is made while the metal is at an elevated temperature and after expansion has taken place, consequently on cooling down to normal temperature the weld resists the metal's returning to its exact original volume. This is a natural phenomenon and cannot be altered, but the distortion or buckling caused by expansion and contraction can be minimized, localized and to some extent controlled. In welding a fitting to a flat panel it is customary to put an emboss in the panel that is a little larger than the fitting to be welded. This has a tendency to localize the buckling in the area of the emboss and minimize the buckling in the panel itself.

In welding, the difficulties due to contraction during cooling are increased, since the heating is intensely localized. Therefore the repair of an aluminum casting, in which the danger of cracking is great due to the hotshortness of the metal, is not to be undertaken without a reasonable degree of knowledge and a large degree of common sense. Many an expensive casting has been ruined by attempts at repair by self-confident but uninformed amateurs, whereas a specialist in the process can rebuild a crank case equal in appearance and strength to a new casting from a mass of broken parts seemingly ready for the scrap heap.

Torch Manipulation

In the welding of aluminum one of the main points in which the process differs from that of steel is in speed of working. The speed is very much greater than with steel, and the movement along the seam becomes more rapid as the metal becomes heated.

The welding rod is held loosely in the fingers of the left hand, and it is kept in a direct line with the weld. The torch flame is directed centrally so that it melts simultaneously both the edges of the sheet to be welded and also the end of the welding rod. Both sides of the weld must be heated equally so that the edges will melt at the same instant, otherwise a bulky and uneven weld will result. It is also important when starting that the two edges should commence to melt before any filling material is melted. The welder quickly learns to judge the correct instant to commence running up the seam. If the torch is kept at an angle of about 30 deg. to the surface of the sheet (Fig. 2) it will prevent too rapid melting of the metal in a restricted area, and thus avoid melting holes through the sheet. By holding the

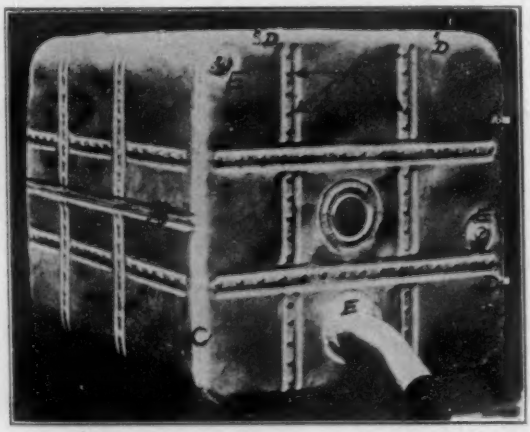


FIG. 6. WELDED ALUMINUM GASOLINE TANK FOR CURTISS PLANE

A—Rivet heads welded to outside of shell; B—Side seam butt welded with Oxy-hydrogen torch; C—Welded corner seam; D—Lugs to hold tank in place welded to shell; E—Connections welded with Oxy-hydrogen torch.

torch at this angle the outer cone of the flame will envelope the metal well ahead of the point of welding, and so will make welding progress more rapid. Care must be taken that the weld penetrate the full thickness of the sheet. However, the torch must not be stopped in any one position for a sufficient length of time to melt holes through the sheet, neither should the inner cone of the flame be allowed to come into contact with the metal. The operator should watch the metal carefully for signs of melting, and fuse the weld metal thoroughly with the molten metal from the sheet. It is not possible to determine the melting point by the color because aluminum does not change color through the entire heat range used in welding. That is, it does not become red hot, but maintains its characteristic silvery white color even in the fluid state.

Welding Commercially Pure Aluminum

The assembly of parts before welding is gone about as in welding steel sheet of the same thickness. Long seams should be tack welded

progressively from end to end at intervals of three or four inches in order to prevent the edges slipping by each other. Intermittent tack welding produces an unsightly weld and is likely to cause cracks. After tacking, the flame of the torch is played upon both edges of the pieces simultaneously causing them to melt, and, the oxide being removed by the flux, the molten edges flow together and coalesce. Only a very small part of the metal is melted at any one time, so that the molten metal is prevented by surface tension from dropping away. The welder progresses rapidly along the seam, the edges melting under the torch and solidifying almost immediately as the torch passes on. In welding long seams, if pronounced buckling starts by the metal shrinking in or out, it should be straightened by hammering before proceeding further with the welding. When a welding rod is used, the tip of the rod should be held in the flame near the metal. Metal from the welding rod is flowed into the weld by the flame as the heat in the puddle alone is not sufficient to melt the rod. The welder should make sure that the added metal fuses thoroughly with the base metal. The weld should be built up 1/16 to 1/8 inch above the surface of the base metal. The weld should be completed as rapidly as is consistent with good workmanship, using a flame of minimum size.

When the joint is completed every portion of the seam will have been melted and solidified again, hence the metal in the weld is in the cast state.

In the case of hard rolled pure aluminum sheet the zones on either side of the weld usually constitute the weakest part, for the thickness at the weld itself can be increased by the addition of welding rod, and the weakness of the cast structure at the weld counteracted by this means. The annealed zones on either side of the weld remain, however, so that whatever the original temper of the metal the final strength will be about 14,000 lb. per square inch.

Welding Alloy Sheet

Simple alloys are readily welded in the same manner as commercially pure aluminum sheet, and the same sort of conditions apply. Thus, hard rolled sheets, after welding, will exhibit the three zones.

(1) Cast metal at the weld.
(2) Softened regions on either side.
(3) The remote parts of the metal which have not been affected by the heat of welding.

With heat treated alloys such as 17S, 25S and 51S it might be expected that if the whole object is submitted to heat treatment after welding the original strength could be regained. However, these alloys in the cast condition are much less susceptible to heat treatment than the wrought metal. Therefore, while the partially annealed zones on either side of the weld would respond to heat treatment, the cast metal in the weld would be much less affected.

In the case of heat treated alloys, the area on either side of the weld is not completely annealed. A series of Brinell impressions was made

on welded specimens of 0.064 in. heat treated 51S sheet to determine to what extent the heat of welding affected the temper of the sheet. The results of this survey are shown graphically in curves of Fig. 1. Curve No. 1, which represents the condition found to exist in heat treated 51S sheet as welded, shows that at a point 1/4 in. from the weld the sheet is in the heat treated condition. At a point one inch from the weld, which was found to be the softest area, a very slight annealing has taken place. The Brinell number for fully annealed 51S sheet is about 28, while the Brinell number at this soft area is 50. The Brinell number for heat treated 51S sheet is about 63. For the heat treated and artificially aged material the Brinnel number is about 95. As we move farther away from the weld, the Brinell numbers show an increase in hardness until a maximum is reached at a point three inches from the weld. This point represents an area in which a slight artificial aging has occurred. Beyond this area there is a slight decrease in hardness until a point four inches from the weld is reached. Beyond this point the temper of the sheet has not been affected by the heat of welding.

Curve No. 2 represents the condition found to exist in a specimen of heat treated 51S sheet that was artificially aged after welding. In the partially annealed area one inch from the weld aging has not had much effect. However, at a point two inches from the weld, the sheet has been fully aged.

Duralumin is extremely hot short and care must be taken to avoid contraction strains when welding this alloy. Such strains may be minimized by preheating or when this is not feasible, by observing such a sequence in assembling the article to be welded that the metal adjacent to the weld will be free to contract without setting up undue strains on the weld. Perhaps one of the best means of preventing cracking from contraction strains is to use a 5 percent silicon welding rod. As previously stated, this alloy has a lower melting point than duralumin, hence remains molten after the base metal has solidified. This permits the weld metal to fill in the voids caused by the solidification contraction of the base metal. Furthermore, the stresses due to contraction shift their effects from the base metal to the weld metal, which being free from hot shortness, will stand the stresses without the development of cracks.

Welding Castings

When a broken aluminum casting is to be welded, it should first be cleaned carefully, removing every trace of oil, grease and dirt by means of a wire brush and gasoline. Unless the casting has a very heavy cross section, it is not necessary to tool the crack or cut out a vee. If the casting has a piece broken out of it, the piece or pieces should be held in correct position by light iron bars and appropriate clamps, the clamps being so attached as to avoid straining any portion of the casting, especially the thin walls (when near the melting point the metal is very weak and will crumble under slight strains). The casting, particularly if a large one, should be preheated. Many expert welders are able to do splendid work without preheating, but this ability results from long

experience. If the casting to be welded is small, or if the weld is near the edge and in a thin walled section, the torch flame may be played over the pieces so as to preheat them before starting to weld. The cold aluminum should be heated slowly. A quick heat will crack the metal near the flame.

To again consider the broken crank case already mentioned, as soon as the casting is properly preheated, it is tack welded. Then starting at the middle of the break weld toward the ends. Welding rod is added by holding the tip of the rod in the flame near the metal. Contrary to welding practice on steel or cast iron, the weld metal must be flowed into the weld by the flame, because the heat in the puddled metal will not melt aluminum. When a few drops are melted off the welding rod, it is worked around and into place with a rubbing motion of the rod. Care must be taken to get the new liquid metal to the bottom of the crack, all the time playing the torch about freely, but always with the tip about two inches from the metal.

When the weld is finished the casting is annealed by adding four or five handfulls of charcoal and covering the furnace top with asbestos paper. The fire is allowed to burn out slowly and the casting cooled in the furnace.

A charcoal furnace is not necessary when filling holes in castings. The area is preheated locally by playing the torch about the hole. The hole should be shaped up so as to remove all pockets and to permit proper manipulation of the torch. In filling blowholes the cavity should be thoroughly cleaned so that only clean metal is exposed. The preparation of a tooth for filling by a dentist is an analogous operation.

For filling holes and welding castings, it is usually preferable to use a weld metal of the same composition as the casting. However, in the case of complicated castings where severe contraction strains are liable to ensue, 5 per cent silicon welding rod would be more desirable.

A flux should be used when welding aluminum castings just the same as for sheet aluminum, however, there is no objection to puddling also, Puddling will merely break up the oxide film and leave it incorporated in the weld metal, thus weakening the weld. The flux will float the oxide particles to the surface and leave a clean sound weld.

Finishing

As soon as the weld is finished and the work has had time to cool it should be thoroughly washed to remove all traces of flux. If the flux is permitted to remain on the weld it will cause corrosion. Therefore it is very important to be sure that every trace of flux is removed, particularly if the completed job is to be painted. Merely cleaning by means of hot water and a scrubbing brush is not sufficient or thorough enough to remove the flux that may be in crevices or cracks which are not readily attacked by a brushing operation. A more effective method of removing the flux is by means of a steam jet, the steam jet impinging upon the welded joint. When a final sand blasting operation is used, the steam jet should be used both before and after sand blasting. A still more efficacious scheme for removing the flux is to wash in a hot

2 per cent nitric acid solution or a warm 10 per cent sulphuric acid solution. In general, the flux removal may be very efficiently performed by first thoroughly soaking the welded article in a "First Wash" tank of hot water for about three minutes, during which soaking period the welded joint should be thoroughly scrubbed with a brush to insure the removal of the bulk of the flux. The article is then dipped in the acid tank for from three to five minutes, after which it is again dipped in the first wash tank and then thoroughly rinsed in a "Final Rinse" tank of hot water. The washed articles, if small, may be dried in sawdust.

Welds in aluminum are quite often untouched after completion, especially in the case of thin sheet metal, where the weld should be so even that it is not unsightly. When desirable the weld can be made completely invisible by grinding off the excess metal and polishing the whole.

Welded Aluminum In Aircraft Construction

Welded aluminum joints have not been looked upon with much favor by the designers and builders of aircraft. However, such joints are being used to some extent, particularly in gasoline tanks. Figure 6 shows a view of a welded gasoline tank built for the Curtiss Company. These tanks, which have a capacity of 113 gallons, are built of light gauge sheet aluminum. The baffle plates are held in place by rivets, the rivet heads being welded to the outside of the tank where they come through to prevent leaks. All seams and all connections in the shell of the tanks are torch welded.

After welding the tanks are washed in warm water to remove the greater portion of the flux. They are then submerged for an hour in a warm 10 per cent sulphuric acid solution to dissolve and remove all traces of the flux, after which the tanks are washed for one hour in running water. The tanks are then tested by connecting a hose and completely submerging the tank in water, forcing in air and looking for leaks, which would be indicated by bubbles of air rising to the surface of the water. A mercury column is used for indicating the pressure as a pressure gauge is not considered accurate enough at these pressures.

Conclusions

The factors which have been discussed are the ones which, if not properly controlled or handled, offer the greatest potential difficulties in welding aluminum. However, the welding of aluminum, and excellent welding too, is not a really difficult process. Welding is a metallurgical process and is, consequently, governed largely by natural laws. Excellent consistent results will be obtained if the principles involved are understood and employed correctly. This is shown by the fact that excellent welding of aluminum is done day in and day out all over the world.

Report
of
Comparative Transverse Bending Tests
on
Welded 20″ I Beams
for the
Electric Arc Cutting and Welding Co.

W. J. KREFELD†

GENERAL

THE tests recorded herein were made upon three Carnegie 20 in. I-65.4 lb. beams, 12 ft. long. One of these beams was continuous and not spliced. The other two beams had been connected at mid-length by welding. The method of connecting the two sections of these beams was as follows:

Specimen No. 2. This specimen consisted of two 6 ft. lengths of 20 in. I-65.4 lb. beams butted together at the ends and joined by arc welding in which metal was deposited across the joint on both sides of the beam. This welding metal was deposited across the joint over the full depth of the beam including the upper flange, web, and top of the lower flange. In addition to the deposition of metal across the joint, a ¾ in. x 6¼ in. x 24 in. steel plate was welded to the lower flange, as a splice plate, this plate being attached to the bottom of the flange, by welding along the outside edges.

Specimen No. 3. This specimen consisted of two 6 ft. lengths of 20 in. I-65.4 lb. beams butted together at the ends and joined by depositing welding metal across the joint on one side of the beam and by attaching a splice plate across the joint on the other side. On the side joined by the deposition of welding metal across the joint the method was similar to that of beam No. 2. On the other side, the upper flange was again connected by the deposition of welding metal, but the web was connected by a ½ in. x 17½ in. x 24 in. splice plate welded to the flange fillets along the top and bottom edges, and welded to the web at each end of the plate for a length of 5½ in. at the center of the web (i.e. not a continuous weld along the edges for the full height of web). In addition to the above connection a ¾ in. x 8 in. x 24 in. plate was welded to the bottom of the lower flange by welding along the outside edges, thus connecting the edges of the flange to the plate.

†Engineer of Tests, Testing Laboratories, Dept. of Civil Engineering, Columbia University.

Fig. 2 attached herewith gives the dimensions of the connections described above.

The specimens tested were submitted by the Electric Arc Cutting & Welding Co. The tests were witnessed by Gilbert Serber, C. E., and M. Stadtfeld, Assistant Engineer, Board of Transportation, New York, N. Y.

Method of Test:

Each of the beams was supported on rocker supports with a span of eleven (11) feet, center to center of supports. These supports provided

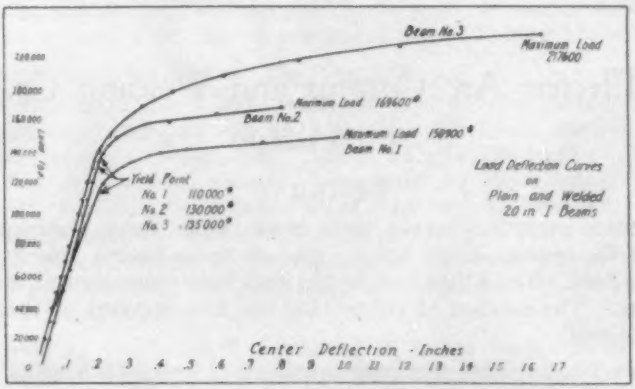


FIG. 1. GRAPH OF RESULTS OF BENDING TESTS

a four (4) inch bearing across the full width of the flange. Load was applied by a 400,000 lb. Olsen Testing Machine at mid-span. The load was distributed to steel blocks 4 in. wide laid across the upper flange and spaced 6 in. apart, thus actually resulting in two concentrations close together at mid-span. This method was adopted in order to ensure a uniform bearing in the case of the welded beams which had welding metal over the joint on the top of the upper flange rather than apply the load directly to the weld. The bearing blocks thus straddled the weld. The continuous plain beam was tested with the same load application for comparison.

Deflection of the beam was measured by means of a fine steel wire kept taut between points on the lower flange directly over the support and a steel scale reading to 0.01 in. attached to the lower flange at mid-span. The center deflections were recorded at increments of 10,000 lb. applied to the beams.

Load was continued until buckling was produced, i.e. maximum load.

Results of Tests:

The following tables give the loads and corresponding center deflections as recorded during these tests. Accompanying this report these data are sown grapically by curves on Fig. 1.

Log of Transverse Bending Tests on 20 In. I-65.4 Lb. Carnegie Beams

Specimen No. 1—Plain beam, continuous.
Span—11 feet.
Loading—Central.

Applied Load, Lb.	Center Deflection, In.	Applied Load, Lb.	Center Deflection, In.
10,000	0	90,000	.15
20,000	0	100,000	.175
30,000	.04	110,000	.195
40,000	.055	120,000	.225
50,000	.06	130,000	.27
60,000	.095	140,000	.41
70,000	.11	146,000	.74
80,000	.13	150,000	.99
		150,900 Max. Load	1.24
		Permanent Set	1.00

Remarks: Beam failure. Pronounced center buckle in top flange.

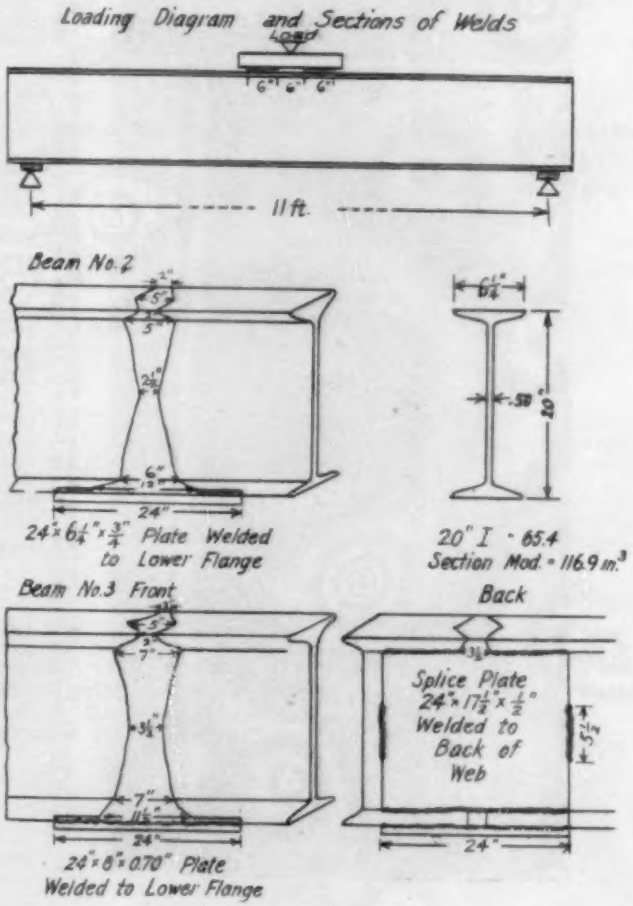

Loading Diagram and Sections of Welds
Load
11 ft.
Beam No. 2
24" × 6¼" × ¾" Plate Welded to Lower Flange
20" I - 65.4
Section Mod. = 116.9 in.³
Beam No. 3 Front
Back
Splice Plate 24" × 17½" × ½" Welded to Back of Web
24" × 8" × 0.70" Plate Welded to Lower Flange

FIG. 2

FIGS. 3 AND 4. TESTS SPECIMENS MADE TO SHOW THE EFFECT OF BENDING LOADS WITH SPLICED PLATES WELDED TO THE JOINT IN DIFFERENT POSITIONS. PLATE SHOWN AT RIGHT IS UPSIDE DOWN. NO PLATES WERE WELDED TO THE TOP FLANGE

Log of Transverse Bending Tests on 20 In. I-65.4 Lb. Carnegie Beams

Specimen No. 2—Welded beam with metal deposited on both sides and plate welded to bottom flange.
Span—11 feet.
Loading—Central.

Applied Load, Lb.	Center Deflection, In.	Applied Load, Lb.	Center Deflection, In.
10,000	.01	100,000	.145
20,000	.04	110,000	.16
30,000	.055	120,000	.18
40,000	.06	130,000	.20
50,000	.08	140,000	.22
60,000	.09	150,000	.265*
70,000	.10	160,000	.44
80,000	.11	165,000	.59
90,000	.13	169,600 Max. Load.	.81
		Permanent Set	.59

Note:* Start of slight top flange buckle.
Remarks: Beam failure. Pronounced center buckle in top flange.
No visible effects in weld.

Log of Transverse Bending Tests on 20 In. I-65.4 Lb. Carnegie Beams

Specimen No. 3—Welded beam with metal deposited on one side and splice plate welded to other side and plate welded to bottom flange.
Span—11 feet.
Loading—Central.

Applied Load, Lb.	Center Deflection, In.	Applied Load, Lb.	Center Deflection, In.
10,000	.01	130,000	.195*
20,000	.03	140,000	.21
30,000	.04	150,000	.24
40,000	.05	160,000	.35
50,000	.06	170,000	.35
60,000	.075	180,000	.45
70,000	.095	190,000	.62
80,000	.11	200,000	.86
90,000	.125	209,000	1.18
100,000	.14	210,000	1.19
110,000	.15	215,000	1.40
120,000	.165	217,600 Max. Load	1.65
		Permanent Set	1.30

Note: *Start of slight buckle in top flange on one end.
Remarks: Web buckling on one end from center toward end accompanied by pronounced top flange buckle on same end in a direction away from the side with the splice plate. Slight buckle in bottom flange in opposite direction to that of top flange.
No visible effects in weld.

Hints on Heavy Cutting

Correct Practices in Production and Demolition Using the Oxy-Acetylene Process and Oxygen Lance

A. G. WIKOFF†

EVEN after considerable experience in cutting metals with the oxy-acetylene blowpipe, it is difficult to realize that the operation is not one requiring mechanical force or great physical effort. This is particularly noticeable when an operator attempts to cut material much heavier than that to which he is accustomed. There is an almost universal tendency to use an unnecessarily high oxygen pressure, acting apparently on the theory that high pressure is necessary for heavy cutting.

This mistake, which is a very natural one to make, is probably the most frequent cause of trouble in attempting to cut heavy sections with the blowpipe. The oxy-acetylene cutting process depends upon the chemical reaction between oxygen and red-hot iron or steel. The iron actually burns so that the action is quite analogous to an ordinary fire. Sufficient oxygen must be supplied to keep the iron burning properly, but an excess may interfere with the action just as too much draught will blow out a fire.

Assume, for example, that an operator, in attempting to cut a 10-in. billet or slab of steel, inserts the largest size nozzle in the cutting blowpipe and adjusts the oxygen pressure to 175 lb. per sq. in. The cut will start all right but difficulty will be experienced in penetrating completely through the slab. After a time the cut will stop and examination will show a rounded cavity at the bottom of the cut. The natural tendency in such a case is to exclaim: "No wonder it wouldn't cut; there was a blowhole." As a matter of fact, this cavity was not present in the slab but was formed during cutting by the excess oxygen. The excess oxygen cools the hot slag and metal so that it does not cut cleanly but swirls around the bottom of the cut and soon forms a cavity of considerable size. This action is illustrated diagrammatically in Figs. 1 and 2.

If instead of using 175 lb. pressure the operator had set his oxygen regulator to deliver 150 lb., it is probable that the cut would have penetrated entirely through the slab, but the job would still be unsatisfactory, as the cut would appear as in Fig. 3. From this it is evident that the oxygen pressure is still too great, as the swirling action at the bottom of the cut is still present. At the top the kerf might be about 3/16 in. wide, but it would flare out to a width of 1 in. or more on the underside.

Blowpipe manufacturers issue charts showing the correct pressures to be used with their equipment for metal of various thicknesses, and if

†Technical Publicity, The Linde Air Products Co.

the operator under discussion had referred to his chart he would have found that 115 lb. was the correct oxygen pressure for cutting metal 10 in. thick. With this pressure the cut will penetrate completely and smoothly, giving a kerf that is slightly wider at the top than at the bottom.

While correct oxygen pressure is probably the most important factor in heavy cutting, there are other points that should be noted. A little preliminary consideration of the placing of the material and of the

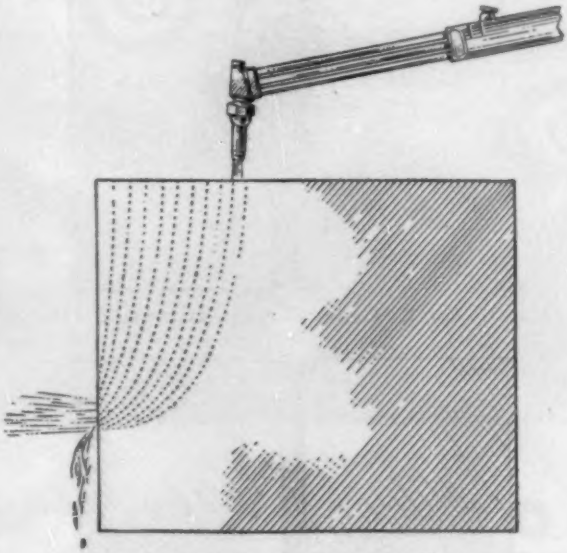


FIG. 1. HEAVY OXYGEN PRESSURE FAILS TO PENETRATE

location of the cut will frequently aid materially in speeding up the work. It is practically always possible to turn the part or to start the cut in such a way that the molten slag will have an opportunity to flow out of the cut freely. Unless this is done on heavy material the excess slag will slow up cutting action. Even with careful attention to these points, considerable practice will be necessary before proficiency can be attained in cutting heavy materials. There is, of course, a limit to the thickness that can be cut with the blowpipe alone when operated by hand.

Where long cuts are to be made in heavy material, a blowpipe mounted in a straight line cutting machine (Fig. 6) is frequently very effective. Use of this equipment covers such widely varying applications as the cutting of huge slabs of armor plate and the removal of exceptionally large risers.

Where heavy sections have to be formed as a step in production work, the shape cutting machine is extremely useful. In this machine, the blowpipe is driven by an electric motor so that its movement conforms exactly to the shape of a templet.

Oxygen Lance

In extremely heavy cutting projects, billets and other large sections which prove too heavy to sever by the use of the blowpipe alone can be cut by means of the oxygen lance used either alone or in combination

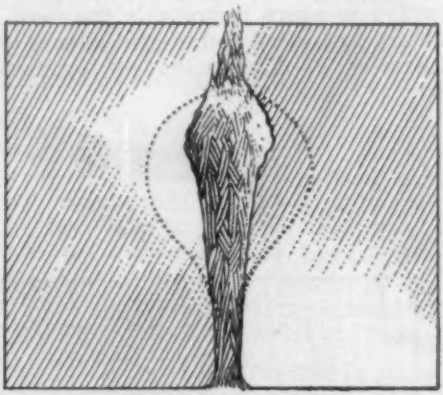


Fig. 2. Cavity Produced by Swirl

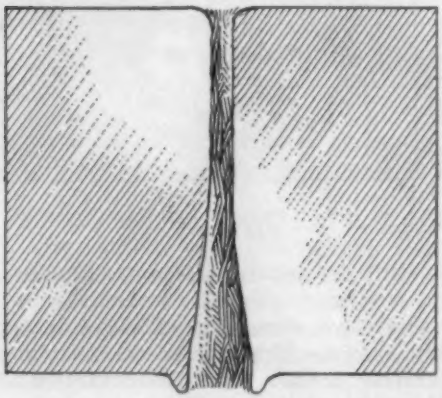


Fig. 3. Pressure Still too High

with a standard cutting blowpipe. With this latter combination, solid metal 8 or 9 ft. thick has been successfully cut, and the ultimate limit has probably not been reached.

An oxygen lance consists essentially of a length of steel pipe connected through an oxygen hose to a regulated supply of oxygen. In setting up an oxygen regulator, at least two cylinders of oxygen should be connected with a properly designed manifold, and the flow of oxygen should be controlled by a manifold regulator which is designed to pass the large volumes of oxygen required by the lance. For connecting the regulator to the lance, standard 7-ply $\frac{3}{8}$-in. oxygen hose is suitable. Pneumatic hose or fittings should never be used as there is always the possibility

that a piece of oily or greasy hose may be used. A piece of 1 in. XX steel pipe about 3 ft. long and bent as shown in Fig. 9 is then connected to the oxygen hose through a reducing coupling and standard oxygen hose connection. This pipe serves as a handle for the lance, permitting the operator to work at one side out of the direct line of sparks and slag produced in the operation.

The lance pipe is connected to the other end of this 1 in. pipe by means of a reducing coupling. For moderately heavy work, ⅛-in. steel

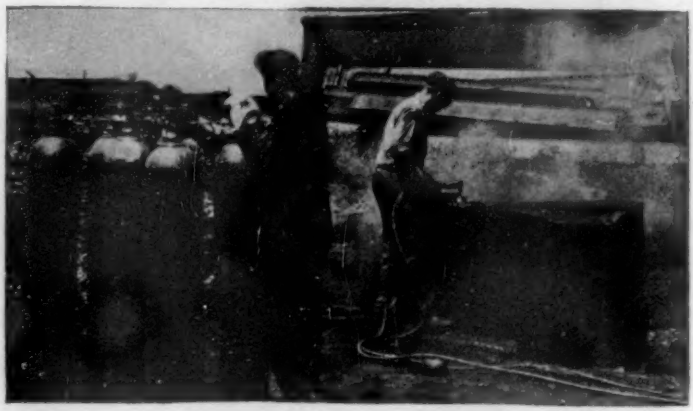


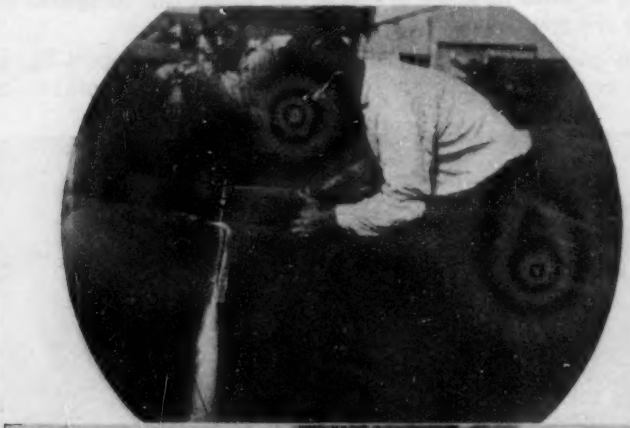
FIG. 4. OXYGEN CYLINDERS MANIFOLDED

pipe may be used for the lance, and even the heaviest work will not require more than ¼-in. pipe. The lance pipe should have ends with easy working threads as it is usually necessary to insert new lengths of pipe during the cutting operation. Each length should be provided with the usual threaded sleeve. All pipe used must be free from oil and grease. Probably the most satisfactory method for removing oil and grease from new pipe is to heat it red hot, thus burning or charring all combustible material.

In operation the oxygen lance differs from the cutting blowpipe in that there are no heating flames to maintain the material at the kindling point. It also differs from the cutting blowpipe in that once cutting has started the lance pipe itself burns and furnishes the heat necessary to keep the cut going. In order to start the oxygen lance, it is necessary to heat a spot on the metal to be cut. This may be done in any one of a number of ways. If a cutting or welding blowpipe is handy, this furnishes the easiest way of heating the metal. Other methods are to place a red-hot rivet or a shovelful of red-hot coals on the spot, or to heat the end of the lance pipe in a fire until red-hot, then when a small stream of oxygen is allowed to pass through the pipe, the red-hot end will burn brilliantly, giving a sufficient heat to start the cut.

In using the oxygen lance it is desirable to have two workmen, one to operate the lance and the other to control the oxygen pressure at the manifold regulator. In starting the lance only a few pounds pressure

is necessary; this is increased as the lance penetrates the metal, the final pressure depending largely on the thickness of the material cut and also to a certain extent on the composition of the metal. Thus the maximum pressure is about 75 lb. for medium carbon or machinery



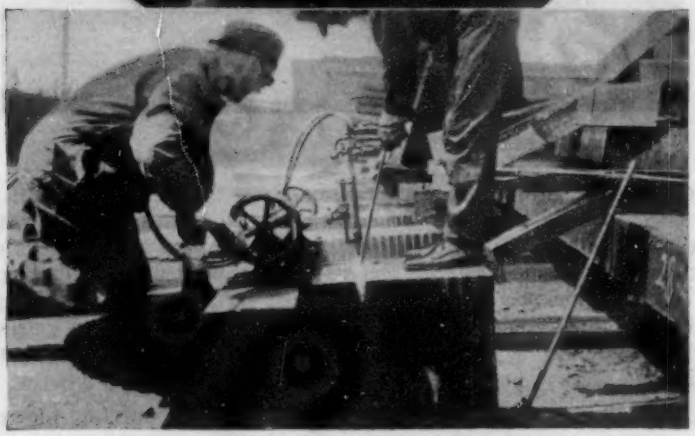


Fig. 5—(Upper). 14 by 24-In. Billet Cut in 12 Minutes.
Fig. 6—(Lower). Straight Line Cutting Machine

steel containing up to 0.50 per cent carbon, and about 100 lb. for low carbon or mild steel. If the job is very heavy, a third workman may be required to change oxygen cylinders and lance pipe.

As noted above, the lance pipe itself burns during the cutting operation so that several lengths of pipe may be necessary on a heavy job. A sufficient supply of pipe should be available so that there will be no delay in making the change.

Used alone, the oxygen lance is more effective in piercing holes than in making cuts. Its piercing action is very rapid, not more than two minutes' actual burning time being required to sink a hole 2½ in. in

diameter, 1 ft. deep, into a hard mass of the thickest iron or steel. This property of the oxygen lance makes it of the utmost value in routine and emergency tapping of blast furnaces, open hearth furnaces, in open-

Fig. 7. Piercing Holes With Lance

Fig. 8. Clean Straight Holes

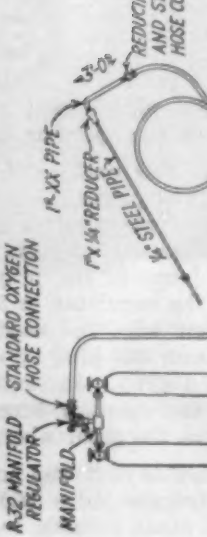


Fig. 9. Oxygen Lance Assembly

ing frozen stoppers on steel ladles, and in drilling holes in salamanders, spills and ladle skulls so that they can be blasted. The details of this work are beyond the scope of the present article.

For piercing small holes accurately, a modified form of oxygen lance is very useful. The oxygen hose leading from the cutting regulator is attached to a carbon burning blowpipe handle. As the sleeve coupling for ⅛-in. steel pipe will fit on the exit nozzles of this blowpipe, a half

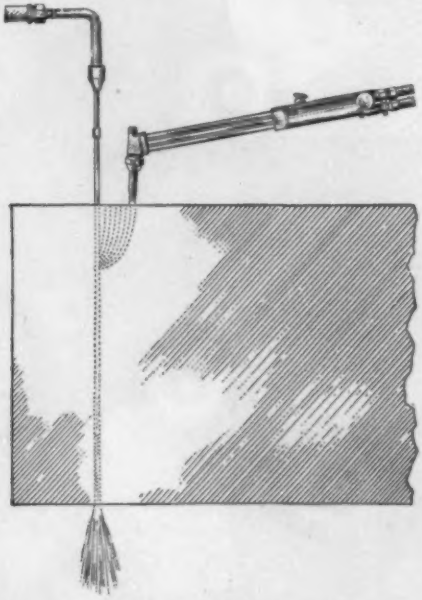


FIG. 10. LANCE AND BLOWPIPE TOGETHER

length of ⅛-in. pipe is used to form the lance. The valve on the blowpipe handle enables the operator to control the flow of oxygen very exactly.

The use of this modified lance may be illustrated by describing how a 2-in. hole was pierced 4½ ft. down the center of a 6-in. shaft. The shaft was first mounted in a horizontal position on rollers so that it could be rotated if necessary, and a simple wooden steady rest was made to hold the lance in the proper position. After adjusting the oxygen pressure at the regulator to 35 lb., the end of the ⅛-in. lance pipe was heated red-hot with the welding blowpipe and a little oxygen allowed to flow through the pipe by opening the trigger valve on the blowpipe handle very slightly. Instantly the end of the pipe began to burn brilliantly, and the operator brought it quickly in contact with the center of the shaft at the point where the cut was to start.

As soon as this part was heated to kindling temperature, the operator opened the trigger valve wider and started the piercing action. The close control made possible by the use of the trigger valve enabled the

operator to pierce the hole very straight along the center of the shaft. Any tendency to get out of line was also corrected by having a helper rotate the shaft 90° at frequent intervals. In this manner a hole about $\frac{3}{8}$-in. in diameter was pierced 24 in. into the shaft. At this point it was found that the hot slag would chill before it could run out of the

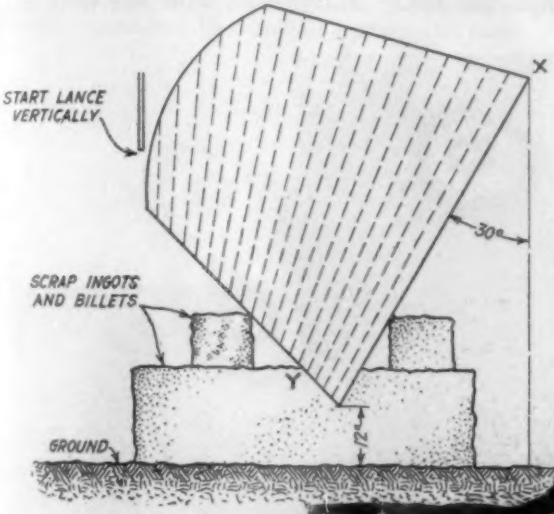


FIG. 11—(ABOVE). THIS GIVES BEST RESULTS

FIG. 12—(RIGHT). 78-IN. SKULL CUT IN TWO

opening. It was then necessary to enlarge the hole to the desired 2-in. diameter by moving the lance back and forth until the hole was of the correct size. The two steps of first piercing a small pilot hole and then enlarging to the correct diameter were repeated on successive sections 8 to 12 in. long until the shaft was completely pierced.

It is obvious that this modified lance may be used very advantageously to pierce small holes very accurately through metal up to about 24 in. in thickness.

Blowpipe and Oxygen Lance

Although the burning of the oxygen lance pipe furnishes heat enough to enable the lance to pierce holes through very heavy masses of metal, the heat is not sufficient to enable the lance to be used in such a way as to produce a cut. If, however, an oxygen lance is used in combination with a standard cutting blowpipe, the latter will furnish sufficient heat to

Fig. 13—(Above). 42-In. Roll Cut

Fig. 14—(Right). Lance and Blowpipe Used

start a cut which the lance will be able to carry through to the bottom of the section.

The procedure for cutting heavy material by this method is as follows: The operator, using the cutting blowpipe fitted with the largest size nozzle and using an oxygen pressure of 100 to 125 lb., starts the cut at one side. The cut will penetrate from 4 to 8 in. into the steel mass, and as the blowpipe advances 2 or 3 in. along the line of cut, a steady stream of white hot slag will start dropping from the bottom of the cut.

At this point an oxygen lance of ¼-in. pipe is brought into action. The oxygen pressure for the lance depends on the variety of steel—75 lb. for medium carbon or machinery steel, and 100 lb. for low carbon or mild steel. The oxygen lance starts rapidly on the hot slag delivered by the cutting blowpipe and carries the cut to the bottom of the section. The lance is then raised to a starting position and again lowered, removing another layer of metal as it descends. The action of the lance is thus somewhat like that of a cross-cut saw.

FIG. 15. 36-IN. STEEL PINION CUT IN 30 MINUTES

It is sometimes possible to dispense with the blowpipe entirely after the lance has had a good start. However, this is possible only where due consideration has been given to the arrangement of the part to be cut. For example, in cutting some solid skulls 5 to 7 ft. in diameter, it was found most important to provide for the free flow of slag out of the bottom of the kerf. On such heavy material a clearance of at least 8 or 10 in. should be provided underneath. It was also found that placing the skull with its axis inclined 30 deg. instead of horizontal enabled the

cut to be made in a similar operation. As shown in Fig. 11, scrap ingots were used to support the skull in the desired position.

This particular skull was the result of a freeze-up of a full ladle of steel, and it measured 78 in. across the top and 78 in. along its axis to the center, the weight being approximately 31 tons. Cutting was started at the point indicated, the cutting blowpipe being used to get a good start. The cutting blowpipe was then removed and the cut was completed with the lance alone. As shown in the illustration (Fig. 11), the cut was started with the lance held vertically, but the lag that naturally developed during the cutting operation caused the cut to assume the direction of the dotted lines. As a result, by the time the lance had reached point X at the top of the mass, the bottom of the kerf had just about reached the lower point of the skull.

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